California High-Speed Train Project

Agreement No.: HSR 13-06
Book 3, Part C, Subpart 1

Design Criteria

HSR 13-06 - EXECUTION VERSION

Prepared for
CALIFORNIA High-Speed Rail Authority

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Chapter 1

General

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Revision	Date	Description
0	02 Mar 12	Initial Release, R0
0.1	Dec 2012	EXECUTION VERSION

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Acronyms

Authority	California High-Speed Rail Authority
CHSTP	California High-Speed Train Project
mph	miles per hour

1 General

1.1 Design Criteria Overview

1.1.1 Purpose and Extent

This document establishes criteria, guidelines and requirements for the design of Infrastructure and Systems elements of the California High-Speed Train Project (CHSTP). Additional guidelines are required for the design of facilities of other owners/operations.

These criteria include design survey and mapping, trackway clearances, track geometry, trackwork, rolling stock and vehicle intrusion protection, civil, drainage, utilities, geotechnical, seismic, structures, tunnels, stations, support facilities, facility power and lighting systems, traction power supply systems, overhead contact system and traction power return system, grounding and bonding requirements, corrosion control, automatic train control, yard signaling, electromagnetic compatibility and interface, supervisory control and data acquisition subsystems, communications, rolling stock–core systems interfaces and, safety and security.

The intended use of these criteria is for final design of the CHSTP, unless indicated otherwise.

1.1.2 Design Standard Classifications

The following terms are used to classify the criteria:

- Recommended – Standard to be equaled or exceeded where there are no major physical, cost or schedule constraints. Designers should use ‘Recommended’ values to the extent practical.
- Minimum/Maximum – Represent limits. Designers shall make every effort to avoid the use of minimum/maximum values. These values are acceptable where constraints make the use of ‘Recommended’ values impracticable.
- “Shall” – Indicates mandatory requirement that must be strictly implemented. Waiver is permissible only under approval of design variance.
- “Should” – Indicates preferred course of action. Design variance is not required if it is not exercised.
- “May” – Indicates permissible course of action within the limits of the standards. Design variance is not required if it is not exercised.

1.1.3 Revisions

Revisions of these criteria, in part or in whole, will be issued by the Authority or its representative. It is the responsibility of the user to base their design on the latest applicable version of these criteria. Refer to the General Provisions for related requirements. Table 1-1

illustrates a Design Criteria revision history. Proposed revisions to the CHSTP Design Criteria may be submitted to the California High-Speed Rail Authority (Authority).

Table 1-1: Document Revision History

Revision Number	Revision Date (DD MMM YY)	Summary Description
0	DD MMM YY	Initial Release

1.1.4 Other California High-Speed Train Project Documents

The following CHSTP documents may be considered with this Design Criteria:

- Standard Specifications
- Standard Drawings
- Directive Drawings
- CADD Manual
- Plan Preparation Manual
- Design Variance Request Process
- California High-Speed Rail Authority and Federal Railroad Administration. 2005. *Final Program Environmental Impact Report/Environmental Impact Statement for the Proposed California High-Speed Train System*.
- *Bay Area to Central Valley Program Environmental Impact Report/Environmental Impact Statement*

1.2 Basis of Design

The CHST system is an electrified steel-wheel-on-steel-rail system with standard gauge tracks that shall meet the following physical, functional, and performance requirements.

1.2.1 Infrastructure

- Fully grade-separated crossings
- Dual-track on the mainline along the entire length with separate station stopping tracks
- Fully access-controlled railway with intrusion detection monitoring systems and intrusion protection systems as required

1.2.2 Traction Power

- Electric traction system – 2 x 25 kV, 60 Hz autotransformer power supply system
- Capable of accommodating a minimum of 12 double trainsets per hour per direction

1.2.3 Train Control and Communications

- Designed to support 3-minute headways
- An automatic train control system targeted to be equivalent to the European Railway Traffic Management System (ERTMS) standard with capability for operating at speeds of up to 220 mph, subject to FRA approval.
- Equipped with high-capacity and redundant communications systems capable of supporting fully automated train operations.

1.2.4 Rolling Stock

- Trainsets using a distributed traction power configuration, approximately 660 feet in length capable of coupling to provide 1,320-foot-long double trainsets
- Seating capacity for approximately 450 to 500 passengers per 660-foot trainset (900 to 1,000 passengers for a 1,320-foot trainset)

1.2.5 Design and Operating Speeds

A design speed of 250 mph where cost-effective and where topographic, geometric, operational, and environmental conditions permit. The design shall allow for sustained operating speed of 220 mph.

In areas where shared-use track is anticipated, such as San Francisco–San Jose and Los Angeles–Anaheim, the maximum design speed is 125 mph.

1.2.6 Trip Travel Times

Governing legislation and other legal documentation dictate characteristics of the CHST system. The requirements are identified in Division 3, Chapter 20 of the Streets and Highways Code.

1.2.7 Comfort

The CHST system shall provide passengers with a comfortable ride experience:

- Ride comfort (smoothness of ride) shall be achieved with lateral and vertical acceleration values equal to or less than 0.05g and 0.045g, respectively, for the maximum design speeds.
- Noise vibration and temperature are discussed in subsequent sections of these criteria.

1.2.8 Safety and Reliability

The CHST system shall:

- Conform to the requirements of applicable U.S. federal, state, and local laws, governing rules and regulations.
- Be fully grade separated at crossings and fully access-controlled.
- Incorporate supervisory control and data acquisition system.
- Incorporate climatic and seismic monitoring systems.

1.3 Regulations, Codes, Standards, and Guidelines

The following sections list the system-wide, international, federal, state, and industry-specific, regulations, codes, standards, and guidelines that have been used in development of these criteria. In addition, the regulations, codes, standards, and guidelines pertaining to each area of design are listed at the beginning of its corresponding chapter. These lists may not include all those applicable. It is the designer's responsibility to determine additional regulations, codes, and standards that are applicable.

Additional, applicable requirements by authorities having jurisdiction over the design, construction, and operation of the facility shall be identified and applied as required for approval.

See General Provisions for precedence of Regulations, Codes, Ordinances, and Standards.

Unless a specific publication edition is identified, the latest edition shall apply.

Deviations from the criteria stated herein require approval from the Authority or its representative and their decisions regarding conflicts shall be final.

1.3.1 Regulations and Codes

Federal and state regulations and codes govern passenger and freight rail systems in the U.S. These regulations are typically the basis of design and govern the operation of conventional rail networks and are neither specifically applicable to the basis of design nor do they govern the operation of HST systems with speeds over 150 mph. As such, international regulations and codes provide additional guidance. Other regulations and codes apply to the design of CHST buildings and facilities and are not specific to the CHST system.

1.3.1.1 International Regulations and Codes

- Technical Specifications for Interoperability (TSI) concerning Trans-European High-Speed Rail
- European Standards (EN for European Norms)

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  - European Committee for Standardization (CEN)
  - European Committee for Electrotechnical Standardization (CENELEC)
  - European Telecommunications Standard Institute (ETSI)
- International Union of Railways (UIC) Code

1.3.1.2 Federal and National Regulations and Codes

- Americans with Disabilities Act (ADA)
- Americans with Disabilities Act Accessibility Guidelines for Buildings and Facilities (ADAAG)
- Code of Federal Regulations (CFR), specifically Title 49 CFR Parts 200-299 and Title 28 part 36.
- U.S. Environmental Protection Agency (EPA) Laws, Regulations, Guidance and Dockets, and Executive Orders
- National Electric Code (NEC)
- National Electrical Safety Code (NESC)
- National Fire Protection Association (NFPA) Codes and Standards

1.3.1.3 State Regulations and Codes

- California Building Standards Code (CBSC), Title 24 of CCR
- California Business and Professions Code
- California Code of Regulations (CCR)
- California Public Utilities Commission (CPUC) General Orders (GOs)

1.3.2 Standards and Guidelines

Standards have been developed by governments, industries, and operators for design and construction to ensure consistency and compatibility among various elements of a rail system. In some cases, fulfillment of standards may be required to secure regulatory approvals from the U.S. Army Corps of Engineers, Division of the State Architect, Office of the State Fire Marshall, California Coastal Commission, Caltrans, and other agencies and authorities.

1.3.2.1 International Standards and Guidelines

- International Electrotechnical Commission (IEC)

1.3.2.2 Federal Standards and Guidelines

- Federal Railroad Administration (FRA) Standards and Guidelines
- Federal Emergency Management Agency (FEMA) Guidelines

- Federal Highway Administration (FHWA) Guidelines
- National Earthquake Hazards Reduction Program (NEHRP)
- U.S. Army Corps of Engineers Guidelines
- U.S. Bureau of Land Management Surveying Manual
- United States Geological Survey (USGS) Standards

1.3.2.3 State Standards and Guidelines

- California Disabled Accessibility Guidebook (CalDAG)
- California Seismic and Safety Commission Standards and Guidelines
- California Occupational Safety and Health Administration (Cal/OSHA) Standards
- California Department of Transportation (Caltrans)
  - Caltrans Bridge Design Manuals, including Bridge Design Specification (CBDS), Bridge Design Practices Manual (CBPD), Bridge Design Aids Manual (CBDA), Bridge Design Details Manual (CBDD), Bridge Memo to Designers Manual (CMTD), Standard Specifications, Standard Plans, Seismic Design Memorandum, Caltrans Seismic Design Criteria ver. 1.4 (CSDC))
  - Caltrans Highway Design Manual
  - Caltrans Plans Preparation Manual and other guidelines for report preparation
  - Caltrans Project Development Procedures Manual
  - Caltrans Standard Plans
  - Caltrans Surveys Manual
  - Caltrans Transportation Management Planning Guidelines
  - Caltrans User's Guide to Photogrammetric Products and Services
  - Caltrans Right of Way Manual, and Forms and Exhibits
- Other Right of Way Publications

1.3.2.4 Industry Standards and Guidelines

- American Association of State Highway and Transportation Officials (AASHTO) Guidance
- American Concrete Institute (ACI) Building Code Requirements
- American Institute of Steel Construction (AISC) Steel Construction Manual
- American Public Transit Association (APTA) Guidance
- American Railway Engineering and Maintenance-of-Way Association (AREMA) Manual for Railway Engineering and Portfolio of Trackwork Plans
- American Society for Photogrammetry and Remote Sensing (ASPRS) Manual

- American Society for Testing and Materials (ASTM) Standards
- American Society of Civil Engineers (ASCE) Guidelines
- American Welding Society (AWS) Codes
- American National Standards Institute (ANSI) Standards
- American Standard Code for Information Interchange (ASCII)
- American Society Of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Guidelines
- American Society of Mechanical Engineers (ASME) Standards and Guidelines
- Underwriters Laboratories (UL) Standards
- Institute of Electrical and Electronics Engineers (IEEE) Standards
- Association of American Railroads (AAR) Standards

1.3.3 Other Jurisdiction

Additional regulations, codes, standards, and guidelines may need to be considered along with site-specific permit and operational requirements. The following are representative agencies, organizations and services that may have specific design standards and specifications, operational and facility requirement that may need to be considered in the design of CHST facilities.

- Air Quality Districts
- Bicycle Coalitions
- City, County, Municipal, Codes, and Ordinances
- City, County, Municipal Utilities Codes, and Standards
- Congestion Management Agencies
- County Transportation Authorities
- Departments of Public Works
- Fire Departments
- Police Departments
- Emergency Responders
- Freight Railroads, Including:
  - BNSF Railway Engineering Standards
  - Union Pacific (UP) Railroad Engineering Standards
- Flood Control Districts

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- Passenger Rail and local Transit Agencies including but not limited to:
  - Amtrak Standards and Guidelines
  - Peninsula Corridor Joint Powers Board (Caltrain) Design Criteria and Engineering Standards
  - Southern California Regional Rail Authority (SCRRA) Engineering Standards
- Parks and Recreation Departments
- Public Utilities Commission(s)
- Regional Comprehensive Planning Agencies
- Regional Council of Governments
- Regional Environment Agencies and Commissions
- Regional Water Quality Control Boards
- School Districts
- Waste Management entities

1.3.4 Precedence of Conflicting Requirements

1.3.4.1 Precedence by Jurisdiction

CHSTP design criteria are specifically applicable to HST facilities within the Authority right-of-way and on tracks on which high-speed trains operate.

Where HSTs operate within another (Third Party) railroad's or transportation's right-of-way, the design requirements of the Authority and the Third Party shall apply.

The design of facilities owned by a Third Party located outside the Authority's right-of-way shall comply with the requirements prescribed by the Third Party.

Where Third Party infrastructure is located within the Authority's right-of-way, the more stringent of the requirements shall apply as required to achieve concurrence of the Authority and Third Party.

1.3.4.2 Precedence by Type of Requirement

In general, applicable regulations and codes take precedence over standards and guidelines. In the case of differing values between the regulations, codes, standards, and guidelines the criterion followed shall be that which results in the satisfaction of all applicable requirements.

Refer to the specific design criteria for applicability of international regulations codes and standards.

1.3.4.3 CHSTP Requirements Precedence of Requirements

See General Provisions for precedence of documents for each Contract Package.

See General Provisions for precedence of design criteria and design standards for Shared Corridor configurations.

See General Provisions for resolution of conflicts for each Contract Package.

1.4 General Design Parameters

1.4.1 Units of Measurement

The CHST system shall be based on U.S. Customary Units, defined by the National Institute of Standards and Technology (NIST). This is consistent with guidelines prepared by Caltrans.

Dual units have been used in this Design Criteria under the following condition: If the source document uses metric units, then the U.S. Customary Units are shown with the metric unit equivalent shown in parenthesis.

Design and construction drawings shall be developed in accordance with the CHSTP CADD Manual.

1.4.2 Milepost and Stationing

Milepost and stationing shall be as defined in the CHSTP Plan Preparation Manual.

1.4.3 Design Variances

Approved design variances are required for design elements that do not meet the limiting (maximum/minimum) design criteria. Requests for variances to design criteria shall follow the CHSTP Design Variance Request Process.

Design variances and exceptions to a Third Party's design standards shall follow the Third Party's design exception process.

Where a design variance is required for both the CHSTP and Third Party, the design exception process for both entities shall be followed.

1.4.4 Professional Licensing Requirement

Documents such as drawings, specifications, and calculations intended for the construction of CHST facilities shall be prepared under the supervision and approval of a licensed professional in accordance with the requirements of Title 16 of the CCR and shall be subject to the limitations of the licensing laws of the state of California.

1.4.5 Third Party Facilities

Unless otherwise stated in the contract documents, the design, construction, replacement or alteration of Third Party facilities shall be done in-kind and in conformance with the published standards of the authority having jurisdiction.

1.4.6 Design Life

Design life for the CHST system infrastructure and systems elements are presented in Table 1-2. These values are intended as baseline requirements for use in defining and assessing design and development standards and requirements, alternative materials and designs, and operational and maintenance activities.

Table 1-2: Design Life

Infrastructure	Design Life
Track and Civil Works, including: • Site, earthwork, line layout, storm drainage • Concrete slab	100 years
with the exception of: • Track, including rails, ties/clips and ballast • Roadway, pavement, parking facilities • Switches and Turnouts	 50 years 50 years 30 years
Structures, including: • Underground structures • Above-ground facilities, including bridges, passenger stations, ventilation buildings • Retaining Walls	100 years
with the exception of: • Support Facilities • Movement Expansion joints, bearings	 50 years 50 years
Mechanical, Electrical, Plumbing, Ventilation and Fire Protection Systems	30 years
Systems	
Traction Power Systems, including: • Traction power supply system (TPS) • Overhead contact system (OCS) support structures and conducts, with the exception of the contact wire, the life of which is dependent upon the number of pantograph passes. • Grounding, bonding, and lightning protection system	50 years
Train Control and Communications System, including: • ATC systems • Yard signal systems and their subsystems • Equipment and supporting cabling • Supervisory Control and Data Acquisition • Communications wired and wireless data transport systems • Communications administrative, control and timing systems • Communications safety, security and fire detection systems • Communications copper and fiber optic cable infrastructure and associated equipment	30 years
Other technology-based systems: • Equipment and non-safety critical, microcontrollers, computers, software and similar commercial off-the-shelf (COTS) equipment	10 years

1.4.7 Standardization

Design shall use standard materials and equipment where possible. Standardization ensures ease of procurement and inventory management, minimizes staff training, optimizes maintenance, and avoids long lead times for materials, equipment, and components.

Equipment and materials shall meet industry standards, be available off the shelf, and supplied by established manufacturers. Selection of equipment and materials shall consider long-term costs, ease of construction and maintenance, and readily available technical support.

1.5 Durability

Design shall assess potential for deterioration of materials and assemblies, including deterioration specific to exposure to the environment. Materials and detail assemblies shall be durable with minimal maintenance and repairs throughout their design life. For surface and assembly for which appearance is important, durability shall include maintenance required to preserve appearance. Design shall take into account the following aspects of durability:

- Control of moisture
- Control of corrosion (including material compatibility)
- Control of ultraviolet light exposure
- Control of exposure to industrial and vehicular pollution
- Minimize damage from wear and tear
- Ease of repair

1.6 Noise Limitation

Noise from construction and operation of the CHST system and ancillary sources shall not exceed limits defined in the following:

- CHSTP Program and Project-specific Environmental Impact Report/Environmental Impact Statement
- FRA's High-Speed Ground Transportation Noise and Vibration Impact Assessment Guideline
- Applicable noise laws and regulations
- Standard Specifications

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1.7 Vibration Limitation

Vibration from construction and operation of HSTs and ancillary sources shall not exceed limits defined in the following:

- CHSTP Program and Project-specific Environmental Impact Report/Environmental Impact Statement
- FRA's High-Speed Ground Transportation Noise and Vibration Impact Assessment Guideline
- Applicable vibration laws and regulations
- Standard Specifications

1.8 Sustainability

1.8.1 Demonstration of High Performance Design

Stations and maintenance facility buildings shall be designed in accordance with CalGreen Code mandatory and voluntary measures, at minimum. "Voluntary Measures" shall be understood to be mandatory. The goal for station and maintenance facility buildings is to optimize the design in regard to site design, energy, water, materials use, indoor air quality, construction practices, and management. A means to demonstrate this optimization may be to use the Leadership in Energy and Environmental Design (LEED), the Living Buildings Challenge, or other appropriate assessment methodology. If such an assessment is used, the rating shall be the maximum feasible.

1.8.2 Water Conservation

The CHST system shall, at a minimum, use water conservation and efficiency guidelines in CalGreenCode mandatory and voluntary sections for all planning, procurement, design, construction, operations, and maintenance of facilities. The goal for facilities is, where appropriate to the climate, to work toward potable water self-sufficiency through consumption reduction, recycling, and on-site capture and storage. Stormwater should be either managed onsite to supply the facility's internal water demands and landscaping, or released for management through acceptable natural time-scale surface flow, groundwater recharge, agricultural use or adjacent building needs.

1.8.3 Energy Conservation

The CHST system shall incorporate energy conservation and efficiency features and operating procedures into the facilities and operating systems to the maximum extent feasible. CHST stations and maintenance facility buildings shall be designed to achieve net-zero site energy, as measured over the course of a year.

1.8.4 Green or Renewable Energy

In operation, the Authority shall produce or procure enough renewable energy to feed into the California grid, equal to the amount facilities and train operation consume. To meet this goal, to the maximum extent feasible, design shall specify the use of building-based and on-site renewable technologies (such as solar, geothermal, wind, biomass and biogas).

1.9 Climatic Conditions

Climatic conditions necessary for design, including those that are site-specific, shall be researched and considered by the designer. Facility- and operations-specific temperatures or conditions are prescribed in the corresponding chapters. Some design elements will consider system-wide extremes and others will be based on the conditions in a specific location.

Table 1-3 presents a summary of corridor climatic conditions by segment. Analyses of climatic conditions shall consider the extreme conditions in the corridor as a whole and/or a particular section of a corridor, as applicable.

1.9.1 Temperature

Areas closer to the Pacific Ocean generally experience more moderate temperatures and less variation in temperature from day to night and summer to winter.

1.9.2 Relative Humidity

Relative humidity varies across the state and by time of year. Coastal areas generally have medium to high humidity year round. Inland, humidity is generally high during the winter and low during the summer. In general, areas further from the ocean have a lower relative humidity. The corridor near Palmdale is in the westernmost range of the Mojave Desert and has low humidity year-round. Weather patterns also influence humidity.

1.9.3 Rainfall

Precipitation for a single day indicates the general rainfall intensity that infrastructure and rolling stock will encounter. The highest record maximum precipitation measured in a day along the alignment occurred in the San Gabriel Range (between Palmdale and Los Angeles). Additional guidance necessary for hydrologic design, such as rainfall intensity, duration and frequency is covered in the *Drainage* chapter.

1.9.4 Thunderstorms

Thunderstorms are relatively uncommon within California but may occur at any time of year. The Bay Area, the Central Coast, and much of the Central Valley experience an average of less than 5 days with thunderstorms each year. The rest of the state experiences 5 to 10.4 mean number of days with thunderstorms per year. Many thunderstorms produce little precipitation,

and fires may result from lightning strikes. When heavy precipitation occurs, flash flooding may result. Severe hail events are uncommon although hail up to 1/2-inch diameter has been reported.

Table 1-3: Weather Conditions by Segment

	Record Extreme Maximum Temperature (°F)	Record Extreme Minimum Temperature (°F)	Mean Number of Days with Freezing Temperatures	Mean Maximum Daily Precipitation (inches)	Annual Record Total Snowfall (inches)	Mean Maximum Daily Snowfall (inches)	Annual Fastest Mile of Wind (mph)	Annual Mean Occurrence of Gust >50 mph	Annual Mean Number of Days with Heavy Fog
San Francisco – San Jose	106–110°	11–20°	0.5–30.4	2.01–2.50"	2.1–6.0"	0.1–3.0"	**41–45**	**2.5–3.4**	15.5–20.4
San Jose –Merced	111–115°	11–20°	30.5–60.4	2.01–2.50"	6.1–12.0"	3.1–6.0"	**41–45**	0.5–1.4	25.5–30.4
Merced – Fresno	**116–120°**	11–20°	30.5–60.4	1.00–1.50"	2.1–6.0"	0.1–3.0"	**41–45**	0.5–1.4	**30.5–35.4**
Fresno –Bakersfield	111–115°	11–20°	30.5–60.4	1.00–1.50"	0.1–2.0"	0.1–3.0"	**41–45**	0.5–1.4	**30.5–35.4**
Bakersfield –Palmdale	111–115°	**–9–0°**	**90.5–120.4**	1.51–2.00"	**48.1–72.0"**	**12.1–15.0"**	**41–45**	0.5–1.4	20.5–25.4
Palmdale – Los Angeles	111–115°	1–10°	30.5–60.4	**3.01–3.50"**	12.1–24.0"	6.1–9.0"	**41–45**	0.5–1.4	15.5–20.4
Los Angeles –Anaheim	111–115°	21–32°	0.5–30.4	2.01–2.50"	0.0"	0.0"	**41–45**	0.5–1.4	20.5–25.4
Los Angeles –San Diego	111–115°	11–20°	30.5–60.4	2.51–3.00"	0.1–2.0"	0.1–3.0"	**41–45**	0.5–1.4	**30.5–35.4**
Sacramento –Merced	111–115°	11–20°	30.5–60.4	1.51–2.00"	0.1–2.0"	0.1–3.0"	**41–45**	1.5–2.4	**30.5–35.4**
Altamont	111–115°	11–20°	30.5–60.4	1.51–2.00"	0.1–2.0"	0.1–3.0"	**41–45**	1.5–2.4	25.5–30.4

This data is included as general information and not for use in application of these design criteria.

Source: National Climatic Data Center (NCDC), National Oceanic and Atmospheric Administration (NOAA). Climate Atlas of the United States: Data Documentation. April 2010. http://www.ncdc.noaa.gov/oa/about/cdrom/climatls2/datadoc.html

Weather Condition Definitions:

Record Extreme Maximum Temperature – Highest temperature recorded in the segment

Record Extreme Minimum Temperature – Lowest temperature recorded in the segment

Mean Number of Days with Freezing Temperatures – Number of days per year on average that temperatures in the segment are below 32°F (maximum value for the segment)

Mean Maximum Daily Precipitation – Maximum precipitation in one day during an average year (maximum value for the segment)

Annual Record Total Snowfall – Maximum amount of snowfall recorded over one year in the segment (maximum value for the segment)

Mean Maximum Daily Snowfall – Maximum snowfall in one day during an average year (maximum value for the segment)

Annual Fastest Mile of Wind – Average speed obtained during the passage of one mile of wind (maximum value for the segment)

Annual Mean Occurrence of a Gust > 50 mph – Frequency of gusts of over 50 mph in 1 year during an average year(maximum value for the segment)

Annual Mean Number of Days with Heavy Fog – Frequency of days with fog resulting in visibility of less than 0.25 miles in an average year(maximum value for the segment)

Notes:

1. Data is provided in ranges consistent with the source data. Specific values will fall within the range provided by more discrete information is not provided.
2. Numbers in bold represent system-wide extreme (maximum/minimum)
3. NCDC archives weather data from the National Weather Service, Military Services, Federal Aviation Administration, the Coast Guard, and volunteer observers. NCDC has a database of U.S. climate data and maps that portray the climate of the U.S. by such elements as temperature, precipitation, snow, wind, and pressure. The period of record for most of this data is 1961 to 1990.
   National Climatic Data Center, National Oceanic and Atmospheric Administration. Climate Maps of the United States. http://cdo.ncdc.noaa.gov/cgi-bin/climaps/climaps.pl

1.9.5 Wind

California is within a zone of prevailing westerly wind and is east of the semi-permanent high pressure area of the northeast Pacific Ocean. The basic flow of air is from the west or northwest for most of the year. However, mountains and other local terrain deflect and funnel these winds and wind direction may reflect other local factors besides prevailing circulation. During certain times of year, strong, gusty, dry winds with speeds that may exceed 100 mph flow from the east into the Central Valley and southern California; this wind is commonly referred to as “Santa Ana Wind.” A similar condition leads to “northers” in the Sacramento and San Joaquin Valleys, which lead to warmer temperatures and a dry, persistent wind.

The fastest mile of wind, or average speed obtained during the passage of one mile of wind, is the metric for measuring constant wind speeds and normalizes the erratic nature of wind flow. For all segments, the annual fastest mile of wind is 41 to 45 mph. Maximum wind gusts at locations along the alignment are provided in Table 1-4.

Tornados have been reported in California but only about once or twice a year. They are rarely severe.

Table 1-4: Maximum Wind Gust for Locations near Alignment

Monitoring Location	Gust (mph)
San Francisco International Airport	**74**
Mountain View/ Moffett Naval Air Station	64
Fresno	54
Bakersfield	46
Edwards Air Force Base	75
Palmdale	63
Los Angeles City Hall	49
Santa Ana/El Toro Marine Corps Air Station	68
Riverside/March Air Force Base	56
Camp Pendleton Marine Corp Air Station	51
San Diego	64
Stockton	46
Sacramento	74

Notes: The climatic wind data contained in this summary was extracted from the NCDC's Local Climatological Data publication, Navy and Air Force climatic briefs, and other sources. The total period of this summary is 1930-1996. The period of record (POR) for which wind data is summarized varies for individual sites and may begin and end at any time during the 1930-1996 period. All available wind data is provided regardless of POR or source. http://www.ncdc.noaa.gov/oa/mpp/wind1996.pdf

1.9.6 Dust Storms

Dust storms occur occasionally along the HST alignment. Dust storms require dry and windy conditions and are most common near dry lake beds and agricultural areas. They are least common in highly urban areas. Dust storms have historically been the most severe in the Central Valley. They also occur in conjunction with wildfires and agricultural burning. Wildfires and other large fires are relatively common and may result in smoky conditions far away from the location of the fire.

1.9.7 Fog

Heavy fog occurs throughout the state, resulting in visibility less than 0.25 miles.

1.10 Elevation and Air Pressure

Elevation along the alignment rises above sea level approximately 3,000 feet across Tehachapi Pass, 3,225 feet across the San Gabriel Mountains and 1,300 feet across Pacheco Pass. Air pressure varies widely based on elevation and weather conditions.

1.11 Air Quality

State air quality condition data is gathered and disseminated by the California Air Resources Board (CARB). Summary air quality conditions are provided by county and by air basin. The alignment includes the following California air basins:

- Sacramento Valley
- San Francisco Bay Area
- San Joaquin Valley
- Mojave Desert
- South Coast
- San Diego County

Emissions that are tracked by CARB include ozone, carbon monoxide, carbon dioxide, hydrogen sulfate, methane, NOx, PM2.5, PM10, sulfur dioxide, and lead. Historic air quality data is available through CARB's Air Quality Data Query Tool (http://www.arb.ca.gov/aqmis2/aqdselect.php).

Chapter 2

Design Survey and Mapping

HSR 13-06 - EXECUTION VERSION

Revision	Date	Description
0	07 Mar 12	Initial Release, R0

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Acronyms

AGPS	Airborne Global Positioning System
Authority	California High-Speed Rail Authority
Caltrans	California Department of Transportation
CHSTP	California High-Speed Train Project
DTM	Digital Terrain Model
GPS	Global Positioning System
PLS	Professional Land Surveyor
QA/QC	Quality Assurance/Quality Control

2 Design Survey and Mapping

2.1 Scope

This chapter provides design survey and mapping criteria for the compilation of topographic mapping and land surveying procedures, performing engineering design land surveys, and generally describes right-of-way mapping requirements. Particular emphasis is placed on accurate field surveys of existing topographic and man-made features required for mapping, and the establishment of accurate terrain models used for design and the development of earthwork quantities.

2.2 Regulations, Codes, and Standards

Refer to the *General* chapter for requirements pertaining to regulations, codes, and standards. Surveys for the California High-Speed Train Project (CHSTP) in general will be based on the California Department of Transportation (Caltrans) manuals and guides. Where applicable, the basis for design survey and mapping standards shall be the most appropriate of the recommended practices described in the following documents:

- California Department of Transportation (Caltrans)
  - Caltrans Surveys Manual
  - Caltrans User's Guide to Photogrammetric Products and Services
  - Caltrans Plans Preparation Manual
  - Caltrans Right of Way Manual
- Bureau of Land Management - Manual of Surveying Instructions (2009)
- U.S. Geological Survey (USGS) - National Map Accuracy Standards
- American Society of Photogrammetry and Remote Sensing - Manual of Photogrammetry

2.3 Quality Assurance/Quality Control

All design survey and mapping and right of way engineering products shall be prepared under the responsible charge and seal of a Professional Land Surveyor, or person registered as a civil engineer prior to January 1, 1982 (pursuant to the California Business and Professions Code, Section 6731 of the Professional Engineers' Act and Section 8731 of the Professional Land Surveyors' Act) licensed in the State of California. All design survey and mapping products used for construction, appraisal and property acquisition, and associated record document tracking and history shall be prepared in accordance with appropriate Quality Assurance/Quality Control (QA/QC) procedures.

A review for the technical correctness of all design surveys and mapping shall be performed using an approved QA/QC procedure. System-wide survey control monumentation has been established by the California High-Speed Rail Authority (Authority) for the CHSTP and will be maintained during design and construction activities by the Authority.

2.4 Survey and Mapping

Design surveys and mapping shall be based on existing system-wide primary and secondary survey control monuments. Geodetic system-wide surveys for the CHSTP have been established. Positional survey data, both horizontal and vertical, for all existing survey control monuments is on file in the office of the Authority and shall be used for all supplemental design surveys and mapping. Design surveys and mapping shall include milepost and location and stationing. The stationing shall be in the same direction as the mileposts.

2.4.1 Horizontal Datum

The horizontal positions of all existing CHSTP survey control monuments are based on the North American Datum of 1983, NAD83 (NSRS2007) as defined by the National Geodetic Survey. The epoch date for all established monument positions is 2007.00. All design surveys and mapping shall include a reference to the horizontal datum NAD83(NSRS2007), and shall include a reference to the epoch date 2007.00. All supplemental design surveys and mapping shall be based on direct horizontal ties to the existing CHSTP survey control monuments.

2.4.2 Vertical Datum

The elevations, also known as orthometric heights, of all existing CHSTP survey control monuments are based on the North American Vertical Datum of 1988 (NAVD88) as defined by the National Geodetic Survey (NGS). All design surveys and mapping shall include a reference to the vertical datum NAVD88. All supplemental design surveys and mapping shall be based on the elevations and direct vertical ties to the existing CHSTP survey control monuments. Any surveys using Global Positioning System (GPS) methods shall use the model GEOID09 for all processing and shall also be based on direct ties to existing CHSTP survey control monuments. The use of precise differential levels shall be used for all critical structures and shall be based on the elevations for the existing survey control monuments established by the Authority.

2.4.3 California State Plane Coordinates and Combination Factors

Design surveys and mapping, right of way engineering, appraisal maps, design and construction for the CHSTP shall be based on the California Coordinate System of 1983 (CCS83), Zone 2 through Zone 6, as defined by the National Geodetic Survey, described in California Public Resources Code commencing at Section 8801. The required use of these State Plane Zones for mapping, also require the use of Combination Factors. The Combination Factors allow for the conversion of horizontal zone (grid) distances to ground level distances and are especially needed for survey construction purposes. All design surveys and mapping shall show the most appropriate Combination Factor as needed. The Combination Factor for each existing survey control monument has been established by the Authority and shall be used for all design surveys and mapping. The Combination Factor for each survey control monument is shown on documents titled Survey Control Monument Data Sheet, on file in the Office of the Authority.

2.4.4 Accuracy and Standards

Surveys performed shall be developed with the accuracy, standards, and field procedures as defined in the Caltrans Surveys Manual. Surveys shall conform to the specifications of accuracy per Caltrans Figure 5-1A titled "Caltrans Orders of Survey Accuracy". Applicable chapters of the Caltrans Surveys Manual include the following:

- Chapter 2 – Safety
- Chapter 5 – Classifications of Accuracy and Standards
- Chapter 6 – Global Positioning System (GPS) Survey Specifications
- Chapter 7 – Total Station Survey System (TSSS) Survey Specifications
- Chapter 8 – Differential Leveling Survey Specifications
- Chapter 9 – Control Surveys
- Chapter 10 – Right of Way Surveys
- Chapter 11 – Engineering Surveys
- Chapter 12 – Construction Surveys
- Chapter 13 – Photogrammetry

Conversion of units from U.S. Survey Foot to international meter may be necessary in order to apply standards listed above. This unit conversion factor is defined as follows:

- 1 U.S. Survey foot = 1200/3937 meters –California Public Resources Code Section 8810

2.4.5 Survey Control

A geodetic control survey has been established for the CHSTP and consists of a network of existing primary survey control monuments at approximate 10-mile intervals. Additional secondary survey control monuments have been established at approximate 2-mile intervals. The existing survey control monuments established by the Authority shall be used both horizontally and vertically for all design surveys and mapping to ensure such surveys and maps are based on the same ground control and that all maps for the CHSTP, based on the California Coordinate System of 1983 (California Public Resources Code, beginning at Section 8801) are uniform and accurate. The network of survey control monuments will be maintained by the Authority.

2.4.6 Photogrammetric and Topographic Mapping Surveys

Different levels of mapping accuracy are appropriate for preliminary and advanced design. Two levels of topographic mapping may be used on the project.

- Photogrammetric mapping at 1"=100' scale controlled using Airborne GPS (AGPS) methods and generating a digital terrain model (DTM) mapping with 2-foot contour intervals is adequate for preliminary design. This mapping will be used to develop pre-final alignments and to determine earthwork quantities for estimating purposes. Field verification by ground level surveying shall be required as part of the mapping effort in order to establish that the product has met the specified accuracy standards. A technical work product report shall be prepared by the mapping team and independently checked by the design teams.
- Fully-controlled photogrammetry generating 1"=50' scale mapping with 1-foot contour intervals to National Mapping Accuracy Standards shall be used by the design teams where greater accuracy for mapping is needed to support detailed design. Field surveys shall be used to check mapping accuracy, match points, bridge and structure sites, critical alignment points, and other CHSTP facilities. The mapping shall meet Caltrans technical standards but shall not follow Caltrans review procedures.

Color digital orthorectified imagery shall be provided as a by-product to the photogrammetry deliverable. Establishment of field survey ground control is required for all photogrammetry and photogrammetric mapping services for 1”=50’ design scale mapping. Field verification by ground level surveying is required as part of the mapping effort in order to establish that the product has met the specified accuracy standards. A report shall be prepared and independently checked.

Topographic mapping shall adhere to U.S. National Map Accuracy Standards. Topographic mapping requirements for preliminary and final design are summarized in Table 2-1 herein.

Table 2-1: Topographic Mapping; Preliminary and Final Design

	Map Scale/ Contour Interval	Max Width of Mapping Coverage	Flying Height / Photo Scale	Expected Resolution	Control	Comment
Preliminary design, to 30%	1"=100' / 2'	3,780'	3600'± AMT / 1:7200, 1"=600'	0.35', pixel	AGPS may be appropriate, with field verification	Detailed planimetrics not obtainable (water valves, manholes, fences, etc.)
Final design, post 30%	1"=50' / 1'	1,890'	1800'± AMT / 1:3600, 1"=300	0.20', pixel	Fully-controlled with multiple ground targets and field verification. AGPS not appropriate	This mapping shall meet Caltrans technical standards for design scale mapping

Notes: AMT = Above Mean Terrain

2.4.7 Digital Terrain Model

Topographic aerial mapping, supplemented by field surveys where needed, shall be used to develop a DTM that mathematically defines the existing ground surface conditions. DTM surfaces shall be used as the basis for defining vertical alignments, preparation of cross-sections, and the generation of earthwork quantities.

The DTM shall be checked for accuracy and adjusted in accordance with Caltrans photogrammetry requirements. The DTM shall be provided in a format compatible with the project design software requirements.

2.4.8 Third Party Topographic Mapping Requirements

Caltrans, railroad operators, municipalities, and utilities generally have unique mapping standards. Available, existing maps as well as new maps prepared by and/or for use by third parties may need to be supplemented, converted, translated, and otherwise adjusted when intended for use on the CHSTP and enabling projects. Any such adjusted maps used for the CHSTP shall conform to the CHSTP datum as specified in Sections 2.4, 2.4.1, 2.4.2, 2.4.3, 2.4.4 and 2.4.5. The quality and accuracy of all such adjusted maps shall be developed to achieve the standards and consistency of the approving agency. All maps requiring modification, shall be converted, translated and adjusted both horizontally and vertically, under the direction of a Professional Land Surveyor as specified in Section 2.3, and shall be positionally equivalent to the CHSTP datum and the existing survey control monuments established by the Authority.

2.5 Right-of-Way Mapping

The proposed right-of-way envelope shall be based on the project footprint and shall consider the site topography, drainage, ditches, retaining walls, service/access roads, utilities, the nature of the structure and side slopes selected, and other CHSTP facilities.

2.5.1 Property Surveys and Right-of-Way Mapping

During preliminary design, assessor's parcel maps and data from County Geographic Information Systems may be sufficient for preliminary design right-of-way mapping. Preliminary right-of-way base maps will be prepared using the project footprint. These maps will be used to identify parcels required for the CHSTP, including full takes and provide information on partial takes to be used for real estate appraisal purposes. Right-of-Way data sheets shall be prepared showing parcel numbers, owner's names, acquisition type, areas, and other information critical for appraisal estimates. Preliminary design should identify properties that may need special attention due to ownership, impacts, or other considerations, so that design and acquisition efforts can be prioritized. Full takes and parcels with willing sellers may be acquired at this stage provided that all State and Federal requirements are met.

During final design, right-of-way appraisal maps shall be prepared for the alignment. These maps will be used to identify the property requirements at a scale defined in the CHSTP Plan Preparation Manual. The tasks involved in preparing these maps include review of title reports, record maps, grant deeds, property surveys, boundary analysis, and preparation of legal descriptions and exhibits for property acquisition. A Professional Land Surveyor, or person registered as a civil engineer prior to January 1, 1982 (pursuant to the California Business and Professions Code, Section 6731 of the Professional Engineers' Act and Section 8731 of the Professional Land Surveyors' Act) shall be in responsible charge of these tasks. Where the project crosses or otherwise impacts the right-of-way of various agencies (i.e., Caltrans, City and County Governments, railroads, utilities, etc.), right-of-way maps shall be prepared as required for the affected agency's approval. Where maps are not required, data showing recordation of parcels purchased by legal descriptions and deeds shall be shown on the Right-of-Way Record Map. Right-of-way engineering preformed during final design and construction shall include monument preservation activities, final monumentation of the right-of-way post construction, and preparation of Records of Surveys as required by the California Land Surveyors' Act.

2.5.2 Right-of-Way Mapping Requirements

Requirements for right-of-way mapping shall be prepared in general conformance with Caltrans policies and procedures. Additional mapping requirements and notes are as follows:

- Right-of-way Appraisal Maps shall include limits and types of acquisition required, property information for affected and adjacent owners, encroachments, vacations, easements required for construction, excess lands and other required interests and uses.
- No spiral curves shall be used to define any lines for right-of-way purposes. Spiral curves shall only be used for track alignments. Circular curves are the only types of curves acceptable for legal descriptions and recording purposes. All curve data and tangent data shall be shown on the right-of-way maps. Tangent lines may be used to show the limits of the right-of-way when the curved track alignments are extremely flat, provided that proper clearance requirements are met. Lines and curves shall always be tangent.
- Right-of-way maps shall show the right-of-way envelope as being continuous and crossing public land as well as private land.
- The limits for the easement areas supporting all new construction (i.e., vent shafts, traction power facilities, etc.) shall be defined geometrically with a minimum of 2 ties shown wherever the location is not contiguous to the right-of-way.
- Separate drawings for vacation or transfer purposes showing the areas of public property or public right-of-way to be closed and utilized for the CHSTP shall be provided. These drawings shall be prepared in accordance with local jurisdictional requirements.
- All necessary survey data shall be shown including monuments, positions, descriptions, line and curve data, offset distances, areas, names, labels, notes, symbols, north arrows, stations, equations, centerline alignment data, milepost, etc for the purpose of acquiring and maintaining right-of-way. All data and references contained in legal descriptions shall be shown on all right-of-way maps.

2.6 Design Survey and Mapping Deliverables

All design surveys and mapping deliverables, supporting documents, and data whether completed or in process, shall be submitted to the Authority.

Chapter 3

Trackway Clearances

HSR 13-06 - EXECUTION VERSION

Revision	Date	Description
0	02 Mar 12	Initial Release, R0
0.1	Dec 2012	EXECUTION VERSION

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Appendix

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Acronyms

GO	General Order
HST	High-Speed Train
OCS	Overhead Contact System
TCL	Track Centerline
TOR	Top of Rail

3 Trackway Clearances

3.1 Scope

This chapter provides design criteria for required clearances to the California High-Speed Train (HST) trackway and facilities. It includes an allowance for HST maintenance equipment and other equipment that may be operated within the HST tracks. Two sets of static, dynamic, fixed equipment, and structure gauge envelopes are presented in this chapter. They have been developed to accommodate the following:

- Tracks that will accommodate high-speed equipment only which includes:
  - The widest and tallest existing HST rolling stock currently under contemplation
  - International Union of Railway (UIC) GC Gauge
  - Association of American Railroads (AAR) Plate C
- Tracks that will also accommodate other passenger train equipment operating in California.

3.2 Regulations, Codes, Standards, and Guidelines

Refer to the *General* chapter for requirements pertaining to regulations, codes, and standards. In addition to the laws and standards relevant to any facility, there are a number of standards specific to railroad facilities that shall be applied.

- Americans with Disabilities Act (ADA)
- California Public Utilities Commission (CPUC) General Orders (GOs) – Clearances adjacent to railroad tracks in California are governed in detail by two CPUC GOs:
  - CPUC GO 26 – Clearances On Railroads And Street Railroads As To Side And Overhead Structures, Parallel Tracks And Crossings
  - CPUC GO 118 – Walkways Adjacent to Railroad Trackage (provides specific minimum widths and locations for walkway areas.)

  Even where not applicable, the GOs provide useful guidance. As legal requirements, these form the Minimum Design Standards.
- Code of Federal Regulations (CFR)
  - Title 29 CFR, Occupational Safety and Health Administration (OSHA)
  - Title 49 CFR, Parts 200-299

- American Railway Engineering and Maintenance-of-Way Association (AREMA) Manual for Railway Engineering
- Association of American Railroads (AAR) Standards

3.3 Clearances to Overhead and Adjacent Structures and Facilities

Minimum clearance requirements shall be as shown on Standard and Directive drawings where applicable. These drawings and the requirements in Tables 3-1 and 3-2 shall be used as guidance in developing clearances for situations and conditions not clearly defined in these drawings.

Where tracks carrying HSTs also carry conventional rail rolling stock or equipment, the clearance requirements of the conventional rail owners/operations shall also be met. Where requirements differ, the larger dimension shall govern.

3.3.1 Vertical Clearances

Minimum vertical clearances shall be measured from the HST top of rail (TOR). Minimum vertical clearances should be carried to a point 25 feet laterally from the centerline of the most outside track.

Table 3-1: Minimum Vertical Clearances

Item	Minimum Vertical Clearance
Clearance from HST TOR to new structures	27’-0” [1]
Clearance from HST TOR to existing structures (V > 125 mph)	27’-0” [1]
Clearance from HST TOR to existing structures (V ≤ 125 mph)	24’-0” [1]
HST tracks span over Road and/or Railroad (HST Overpass)	See Note [2]

Notes:

(1) These clearances assume that the width of the grade separated structure above the HST track is no more than 160 feet. Structures wider than 160 feet require further Engineer approval.

(2) Clearances to be determined by agreements with the third party agency owning the facility.

3.3.2 Horizontal Clearances

Minimum horizontal clearances shall be measured from the track centerline (TCL) of the closest HST track to the feature being cleared.

Table 3-2: Minimum Horizontal Clearances

Item	Minimum Horizontal Clearance
TCL to railroad corridor right-of-way	See *Rolling Stock and Vehicle Intrusion Protection* chapter
TCL to highway edge of travel way	See *Rolling Stock and Vehicle Intrusion Protection* chapter
TCL to face of permanent structure	25'-0" (2) (3)
TCL to edge of platform	5'-9" (1)
TCL to centerline of OCS poles, main gantry and strain gantry	See Standard and Directive Drawings
TCL to face of fixed equipment	10'-0" (3)

Notes:
(1) 5'-9" for preliminary design is based on the half-width of the widest passenger vehicle currently under consideration. Following determination of actual vehicle, the edge of platform shall be located 2-3/4 inches beyond the half-width of the vehicle at the elevation of the floor and at the same height above top of rail as the elevation of the vehicle floor.
(2) Protective structure may be required if horizontal clearance is less than 25 feet.
(3) See Appendix 3.C, 3.D, 3.G, and 3.H for constrained areas.

3.3.3 Clearances to Third Party Facilities

Where facilities owned and operated by third parties are involved, the clearance requirement of this document and those of the third party shall be compared and the larger dimension used.

3.4 Vehicle Clearance Envelopes

The static and dynamic envelopes in Appendix 3.A and 3.E define the maximum vehicle size and limits of vehicle movement including the pantograph. For additional space requirements for pantograph and OCS related facilities, see the *Overhead Contact System and Traction Power Return Systems* chapter.

3.4.1 Description of Envelopes

Appendices 3.A to 3.H define the following limits:

- Static Envelope – The outline that limits the dimensions of the vehicle which takes into account the vehicle fabrication tolerances.
- Dynamic Envelope – Defines the limits of motion of a static outline size and shape vehicle. The effects of curvature and superelevation are defined by widening and rotating the dynamic outline.
- Fixed Equipment Envelope – Defines the closest permitted location of trackside facilities, such as utilities, continuous and intermittent elements including but not limited to the following:
    - Conduits and cables

- Fire water lines
- Signs and markers
- Catenary system features
- Sound/Screen walls
- Signal heads, etc.

- Structure Gauge – Represents the minimum distances to be provided adjacent to the tracks where other considerations do not require a larger distance. The structure gauge defines the closest permitted location of major features, including but not limited to, the following:
  - Retaining walls
  - Bridge elements
  - Tunnel sides, etc.
- Walkway Envelope – Indicates the allowance for walkway space and its closest allowable proximity to the track. The walkway envelope shall be defined as follows:
  - The width shall be no less than 3.00 feet.
  - The vertical clear space shall be no less than 7.50 feet above the walkway surface.
  - The top may be tapered symmetrically from full width at 6.00 feet above the walkway surface to 2.50 feet wide at the top of the envelope.
  - The trackside edge of the walkway shall clear the static envelope and shall clear the dynamic envelope.
- Width and Depth of Area below Top of Rail – Dependent on the trackform used, refer to the *Trackwork* chapter.

3.4.2 Structure Gauge for Non-Electrified Tracks

Certain tracks within maintenance facilities may not require electrification. Structure gauge for these tracks shall be as shown on Appendix 3.C, 3.D, 3.G, and 3.H except that the overhead clearance may be reduced to 19.00 feet.

3.4.3 Effects Due to Curve Radius

Due to swing out of the car ends beyond the bogie positions and swing in of the middle of the car body, the "swept path" of the vehicle body will be wider on curves than on tangent track. Only the car body itself swings out. The lower parts of the Static Envelope and Dynamic Envelope that represent the position of the bogies do not swing out. Since the normal mounting position of pantographs is over the bogies, the swept path of the pantograph does not increase on curves. Those parts of the envelopes representing space for the catenary do not increase on curves, as the catenary is mounted on the structure, not on the vehicle. See Appendix 3.A and 3.E for the location of affected points. The widening of the static and dynamic envelopes shall

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consider lateral clearance requirements on curves for all of the candidate rolling stock. The lateral dimensions determined by the formula below provide for the maximum swing out of the mid car toward the inside of the curve and end of car toward the outside of the curve.

EO (ft) = MO (ft.) = 550 / R (ft.)

Where:

R = radius of the curve,

EO and MO = the increased offset required to clear the vehicles on curves. EO is toward the outside of the arc and MO is toward the inside of the arc.

For large radius curves, the widening may be neglected. The limitations of and methods of applicability of widening of sections is described in the notes of the Appendices.

Table 3-3: *Not Used*

Location of Placement of Transition to Increased Width in Structure Gauge – The usual objective is to ensure sufficient space, not the precise need for additional space. Sufficiency may be achieved by beginning the transition from the unwidened section 75.00 feet into the tangent track beyond the beginning of the spiral, or of the curve if there is no spiral and achieving the full needed additional offset not less than 25.00 feet before the beginning of the full arc.

3.4.4 Effects of Superelevation

Point of Definition of Track Profile – The track profile elevation is defined as the elevation of the top of the inside rail (low rail) of the curve. This point is commonly referred to as the Profile Grade (PG).

Superelevation Measurement – Superelevation is measured, whether with a level board or by survey, by determining the relative difference in elevation between the highest point on the outside rail of the curve and the highest point on the inside rail of the curve. The distance between the points is normally considered as being track gauge plus rail head width. These high points are slightly further apart than the centerline to centerline separation of the railheads due to the rail inclination toward the track center, but this small distance is normally neglected as being insignificant. Standard track gauge is 56.5 inches, measured between points 5/8 inch below the top of rail. Nominal rail head width is 3.0 inches. Thus the distance between points of measurement in the superelevation calculation is taken as being 59.5 inches.

Point of Rotation – The point of rotation of the track is defined as the gauge corner of the inside rail of the curve. Therefore, the point of rotation is at the profile line elevation and offset 28.25 inches from the track centerline toward the inside of the curve.

Widening of Section – The Structure Gauge and Fixed Equipment Envelope will not require widening on large radius curves. See notes on Appendix 3.C, 3.D, 3.G, and 3.H for widening requirements.

3.5 Track Center Spacing

Track center spacing is related to but only partially controlled by the structure gauge dimensions. The distance between HST track centers considers aerodynamics, design speed, and ease of maintenance. The distance between track centers may be increased where the increase is beneficial for maintenance, structural, or constructability considerations.

Track center distances shall be based on design speed (V) in Table 3-4. For track centers in tunnels and trench structures with a separation wall and/or walkway between the two tracks, refer to Standard and Directive Drawings.

Table 3-4: Track Centers

Design Speed / Condition	Recommended (feet)	Minimum (feet)
V > 160 mph	16.50	16.50
90 mph < V ≤ 160 mph	16.50	16.00
V ≤ 90 mph (1)	16.50	15.00
With OCS poles located between tracks	25.00	22.00
Between Main Track to Station Tracks or Sidings	25.00	25.00
Tracks with inter-track fences	22.00 (2)	18.00 (2)

Notes:

(1) For track centers in yards, see the *Track Geometry* chapter. For yard facility requirements, see the *Support Facilities* chapter.

(2) If the walkway is adjacent to the fence, then the distance in the condition “with OCS poles located between tracks” shall be used.

3.5.1 Effect of Small Radii

For small radius curves, the track centers may need to be increased. The required increase is expressed by the following formula:

Increase in Track Centers = Constant / Radius

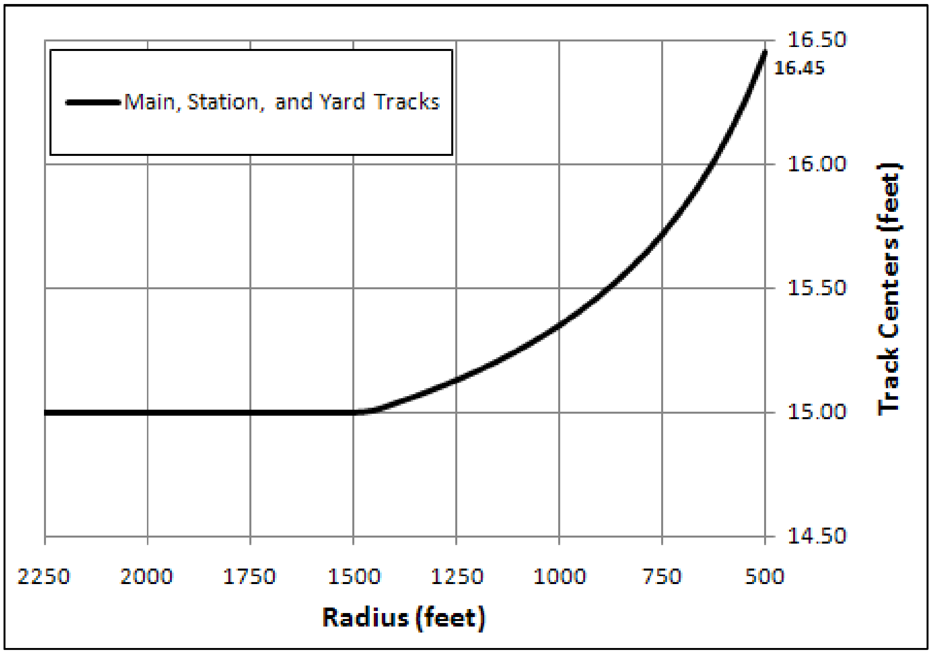
The constant is specific to the truck center and body length dimensions of the vehicle and the units of measurement. For the anticipated range of vehicle dimensions, the formula given below provides sufficient clearances between tracks. The value shall be rounded up. It shall not be rounded down.

Track Centers Increase due to Radius – No widening is required for tracks set at 16.50 feet track centers. For tracks spaced at less than 16.50 feet, the allowed minimum track centers shall be the greater of the defined minimum track centers for straight tracks (15.00 feet) or that determined by adding the value determined by the following formula to 14.75 feet.

Increase in Track Centers (feet) = 1,100 / R (feet)

Where the use of this formula results in a required track center spacing of less than that given for the minimum spacing on straight track, it shall be taken as meaning that no increase in track centers is required. It shall not be taken to mean that track centers may be reduced.

Figure 3-1: Track Centers Required on Small Radius Curves



3.5.2 Effect of Superelevation on Track Centers

In the case of curves under 3,000 feet radius and the inside track having less superelevation than the outside track, additional space is required between tracks. This widening shall be 2 times the difference in superelevation.

3.5.3 Clearance Point

Where tracks connect or cross, the clearance point between tracks shall be equal to the minimum track center spacing for the design speed in Table 3-4.

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3.6 Other Clearance Requirements

3.6.1 Passenger Station Clearances

For passenger station platform offset and elevation dimensions, see the *Stations* chapter.

For track layout along station platforms, see the *Track Geometry* chapter.

3.6.2 Utility Clearances

For utility clearance requirements, see the *Utilities* chapter.

3.6.3 Additional Clearance for Seismic Fault Zones

Additional clearance for seismic fault zones shall be based on fault displacement analysis. Refer to the *Seismic* chapter. The positioning of the additional clearance shall be based on the result of the analysis of the potential magnitude of and direction of ground movement at the location of the fault zone crossing. The length and width of the additional clearance zone shall be such that subsequent to movement of the fault there will be sufficient space so that the required track realignment will permit operation without a permanent speed restriction.

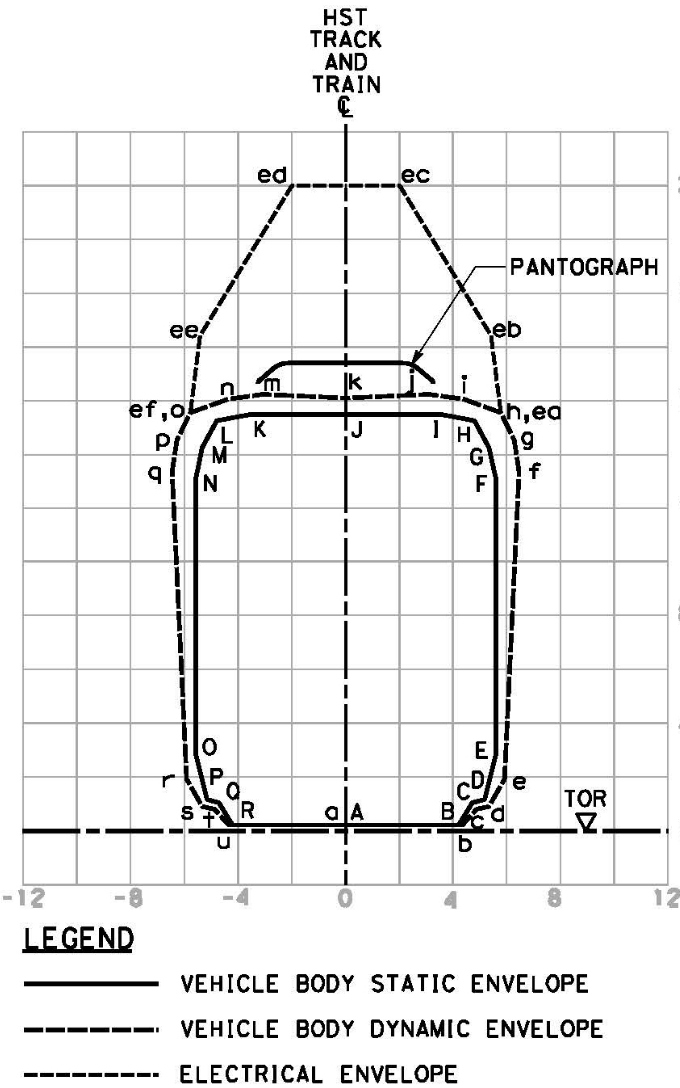
3.6.4 Space Around Turnouts

Space adjacent to turnouts shall be reserved for the mounting of switch machines to move the points, along with power and control cabling for those machines. This space shall be provided along 1 side of Number 9 and 11 turnouts. The space shall be provided on both sides of larger turnouts, including all high-speed turnouts. The space shall begin 10 feet in advance of the beginning of the switch point curve and extend to the point where the centerlines are not less than 0.75 feet apart. For turnouts larger than Number 15, there shall be an allowance for operating mechanisms for swing nose frogs that shall be located where the track center spacing is between 4.50 feet and 5.50 feet. Any curbs or other obstructions that would be higher than the subgrade or invert supporting the track shall be located no closer than 7.75 feet from TCL within these areas.

3.6.5 Space Around Derails

Space adjacent to derails shall be reserved for the mounting of switch machines to move the derail. An additional width of 4 feet shall be provided on the derailing side between a point 50 feet in advance of the derail to 50 feet beyond the derail for block derails or 300 feet beyond the derail for switch point derails. See the *Trackwork* chapter for criteria determining derail types and locations.

Appendix 3.A: High-Speed Equipment Only, Static Envelope and Dynamic Envelope, Tangent Track



Tangent Track		
Point ID	Horizontal Distance from TCL (feet)	Vertical Distance from TOR (feet)
Vehicle Body Static Envelope		
A	0.000	0.229
B, R	±4.208	0.229
C, Q	±4.708	1.042
D, P	±5.167	1.167
E, O	±5.583	2.833
F, N	±5.583	13.083
G, M	±5.333	14.250
H, L	±4.792	15.250
I, K	±3.500	15.500
J	±0.000	15.500
Vehicle Body Dynamic Envelope		
a	0.000	0.229
b, u	±4.354	0.229
c, t	±4.875	0.792
d, s	±5.333	0.896
e, r	±5.917	1.927
f, q	±6.458	13.354
g, p	±6.271	14.527
h, o	±5.771	15.552
i, n	±4.385	16.042
j, m	±3.083	16.229
k	0.000	16.083

Point ID	Horizontal Distance from TCL (feet)	Vertical Distance from TOR (feet) (See Note 6)	
		Open Sections	In Tunnels
Electrical Envelope			
ea, ef	±5.771	15.552	15.552
eb, ee	±5.417	18.417	18.417
ec, ed	±2.000	24.000	22.333

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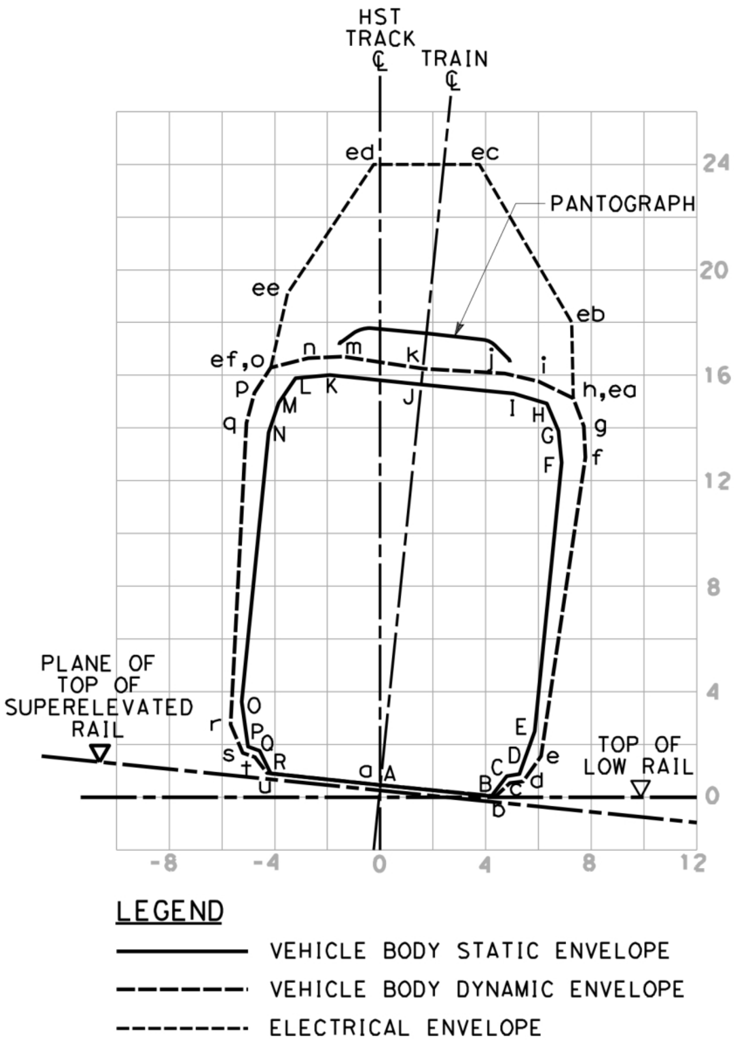
Notes:

1. Definition of the envelopes:
   a. The Vehicle Body Static Envelope defines the maximum shape and dimensions for any vehicle which may be operated on dedicated tracks of the high-speed railroad.
   b. The Vehicle Body Dynamic Envelope takes the static envelope to the physical limits of motion under the maximum conceivable forces combined with the maximum allowable limits of wear and deficiencies including, for clearance purposes, motion due to track deficiencies and misalignments.
   c. The Pantograph is shown as it would be positioned with its center at its nominal elevation of 17.417 feet from TOR, see OCS Standard and Directive Drawings.
   d. The Electrical Envelope is the allowable space for overhead electrical equipment.

2. The Vehicle Body Static and Dynamic Envelopes are based on a combination of in-service high-speed passenger equipment, Association of American Railroads (AAR) Plate C and International Union of Railways (UIC) GC Gauge.
3. The Vehicle Body Static Envelope includes tolerances in the manufacture of the vehicle itself, but no allowances for any motion of the vehicle on the railroad or allowances for uneven wear of components.
4. The Vehicle Body Dynamic Envelope includes the vertical, lateral, and sway motion limits with the maximum allowable limits of wear and deficiencies such as deflated airbags and broken springs under the maximum conceivable forces. For purposes of defining clearances, this dynamic envelope also includes the effects of track conditions and alignment deviations.
5. The total movements assumed in the development of the Vehicle Body Dynamic Envelope are:
   a. Lateral expansion: 3.50 inches
   b. Downward expansion: 4.50 inches
   c. Upward expansion: 6.75 inches
   d. Angular movement: 3.00 degrees – rotated about centerline at a point 16.5 inches above TOR
6. The Electrical Envelope is lower in tunnel sections than in open air sections, however, the width is the same for both cases.
7. The width of the swept path of the vehicle body increases on curves due to mid-car and end-car overhang.
8. The location of the points on the widened swept path of the vehicle body is determined by adding 550/radius (in feet) to the horizontal dimensions for points D, E, F, G, H, I, K, L, M, N, O, P, d, e, f, g, h, i, n, o, p, q, r, and s. The vertical dimensions do not change.
9. Points A, B, C, Q, R, a, b, c, t, and u need not be shifted as they relate to components that are on the vehicle at or near the bogie positions or attached to the structure.
10. Widening may be neglected on tracks with radii of 10,000 feet or larger.
11. Widening shall be calculated before calculating the position of the section due to the effects of superelevation.
12. As an example, the increased dimensions for these points for a curve of 950 feet radius are given in the following table: (That radius is the internal radius of a standard No. 11 turnout.)

950 feet Radius (For other radii, take static values for horizontal distance and add 550/Radius.)					
Point ID	**Horizontal Distance from TCL (feet)**	**Vertical Distance from TOR (feet)**	**Point ID**	**Horizontal Distance from TCL (feet)**	**Vertical Distance from TOR (feet)**
Vehicle Body Static Envelope			**Vehicle Body Dynamic Envelope**		
A	0.000	0.229	a	0.000	0.229
B, R	±4.208	0.229	b, u	±4.354	0.229
C, Q	±4.708	1.042	c, t	±4.875	0.792
D, P	±5.746	1.167	d, s	±5.912	0.896
E, O	±6.162	2.833	e, r	±6.496	1.927
F, N	±6.162	13.083	f, q	±7.037	13.354
G, M	±5.912	14.250	g, p	±6.850	14.527
H, L	±5.371	15.250	h, o	±6.350	15.552
I, K	±4.079	15.500	i, n	±4.964	16.042
J	±0.000	15.500	j, m	±3.083	16.229
			k	0.000	16.083

Appendix 3.B: High-Speed Equipment Only, Static Envelope and Dynamic Envelope Swept Path of Vehicle Rotated for Superelevation



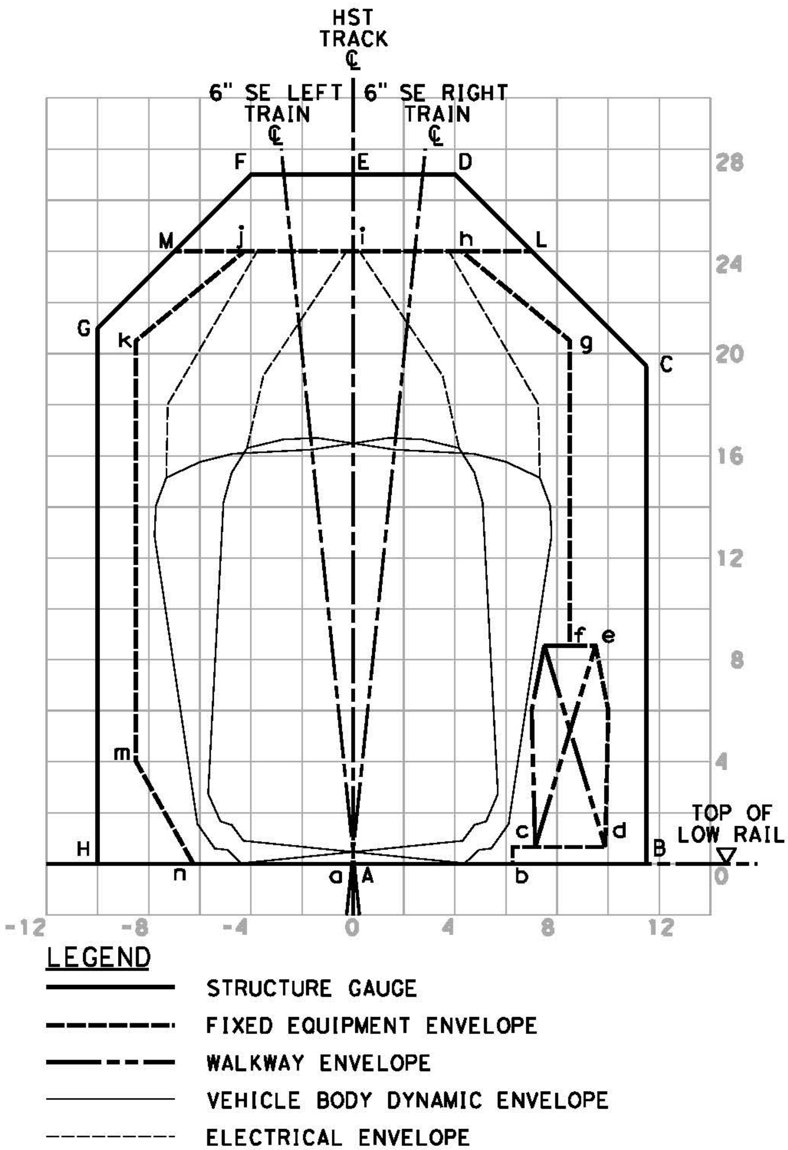
Point ID	Horizontal Distance from TCL (feet)	Vertical Distance from TOR (feet) (See Note 5)	
		Open Sections	In Tunnels
Electrical Envelope			
ea	7.322	15.132	15.132
eb	7.258	18.018	18.018
ec	3.750	24.000	22.333
ed	-0.250	24.000	22.333
ee	-3.520	19.111	19.111
ef	-4.161	16.926	16.926

Superelevated, No Widening (Values for 6 inches superelevation tabulated. See notes for method of calculation for other values.)		
Point ID	**Horizontal Distance from TCL (feet)**	**Vertical Distance from TOR (feet)**
Vehicle Body Static Envelope (Without Increase in the Horizontal Dimension for the Effect of Small Radii)		
A	0.035	0.465
B	4.222	0.041
C	4.801	0.799
D	5.270	0.877
E	5.853	2.493
F	6.886	12.691
G	6.755	13.877
H	6.317	14.926
I	5.057	15.305
J	1.575	15.658
K	-1.907	16.011
L	-3.217	15.893
M	-3.857	14.953
N	-4.224	13.817
O	-5.257	3.619
P	-5.011	1.919
Q	-4.567	1.749
R	-4.152	0.890
Vehicle Body Dynamic Envelope (Without Increase in the Horizontal Dimension for the Effect of Small Radii)		
a	0.035	0.465
b	4.367	0.031
c	4.924	0.538
d	5.409	0.595
e	6.093	1.562
f	7.784	12.876
g	7.713	14.063
h	7.322	15.132
i	5.993	15.759
j	4.716	16.077
k	1.634	16.243
m	-1.419	16.699
n	-2.733	16.644
o	-4.161	16.296
p	-4.762	15.327
q	-5.067	14.179
r	-5.680	2.755
s	-5.204	1.671
t	-4.758	1.521
u	-4.297	0.909

<u>Notes:</u>

1. The tables in this appendix give the position of points on the static and dynamic outlines of the vehicle rotated for 6 inches superelevation and without widening for the effects of curve radius. See the following notes for the method of calculation of the position of these points.
2. Determine the widened and rotated swept path of the vehicle as follows:
   a. Enlarge the width of the vehicle based on the radius of the curve. See Appendix 3.A notes 8, 9, and 10 for method of development of envelope due to curve radius.
   b. Determine the angle of rotation from the applied superelevation as follows: The angle of rotation is arcsin (superelevation/59.5 inches)
   c. Rotate the section by this angle about the point of rotation: The point of rotation for superelevation for both the static envelope and the dynamic envelope is the top inside corner of the inside rail of the curve, located at the track profile elevation and 28.25 inches (2.354 feet) offset from the track centerline.
3. The angle is 5.78756 degrees, or 5 deg 47 min 15 sec for 6 inches superelevation.
4. Points ec and ed do not rotate. They shift laterally a distance of 3.5 times the superelevation. For 6 inches superelevation, this distance is 21 inches or 1.75 feet.
5. The Electrical Envelope is lower in tunnel sections than in open air sections, however, the width is the same for both cases.
6. The Pantograph is shown as it would be positioned with its center at its nominal elevation of 17.417 feet, see OCS Standard and Directive Drawings.

Appendix 3.C: High-Speed Equipment Only, Structure Gauge and Fixed Equipment Envelope, Open Section



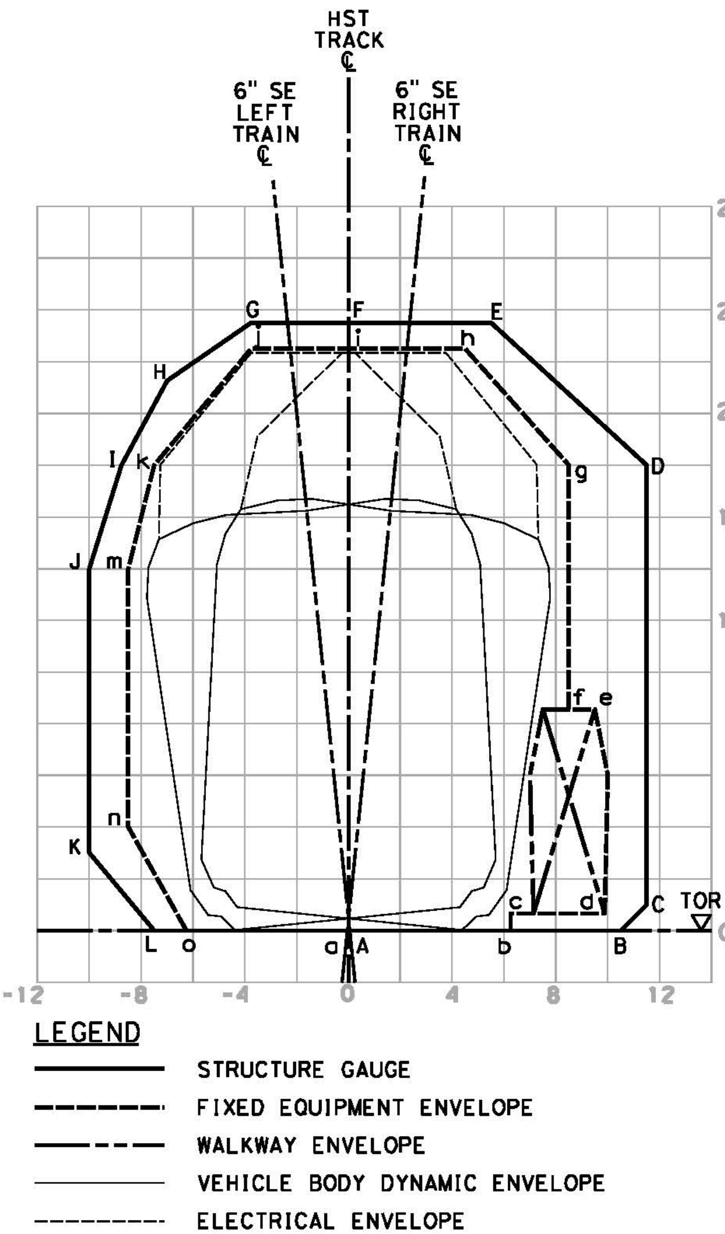
Point ID	Open Section: Horizontal Distance from TCL (feet)	Open Section: Vertical Distance from TOR (feet)
Structure Gauge		
Walkway Side (See Note 3)		
A	0.00	0.00
B	11.50	0.00
C	11.50	19.50
D	4.00	27.00
E	0.00	27.00
Non-Walkway Side		
A	0.00	0.00
H	-10.00	0.00
G	-10.00	21.00
F	-4.00	27.00
E	0.00	27.00
Under Existing Low Overhead Structures		
L	7.00	24.00
M	-7.00	24.00
Fixed Equipment Envelope		
Walkway Side (See Notes 3 & 4)		
a	0.00	0.00
b	6.25	0.00
c	6.25	0.67
d	10.00	0.67
e	10.00	8.17
f	8.50	8.17
g	8.50	20.50
h	4.25	24.00
i	0.00	24.00
Non-Walkway Side		
a	0.00	0.00
n	-6.25	0.00
m	-8.50	4.00
k	-8.50	20.50
j	-4.25	24.00
i	0.00	24.00

Notes:

1. Definition of the envelopes:
   a. The Structure Gauge defines the minimum distances from track to permanent features such as walls, columns and overhead structures.
   b. The Fixed Equipment Envelope defines the allowable space for fixtures such as signs, signals, lights, piping and conduits that will be attached to the permanent features defined under Structure Gauge.
   c. The Walkway Envelope defines a space sufficient for a person to be clear of any track mounted vehicle. The envelope illustrated is 7.50 feet high by 3.00 feet wide with the top 1.50 feet tapering to a width of 2.50 feet. Its precise location may vary depending upon local conditions. Therefore, the location of points b, c, d, e, and f will vary with the location of the walkway.
2. The Dynamic Envelopes for 6 inches superelevation each way are shown to illustrate their fit within the Structure Gauge and Fixed Equipment Envelope. See Appendix 3.B for dimensions of these envelopes.

3. Right side dimensions in the figure and table are those that apply to the walkway side regardless of the actual location of the walkway. Left side dimensions in the figure and table are those that apply to the non-walkway side regardless of the actual location of the walkway.
4. Offset to structure on walkway side shall be 12.50 feet or niches shall be provided as required for placement of larger equipment.
5. Structure shall provide sufficient clear distance below TOR for the track form, under track equipment and other fixtures that must pass under the tracks.
6. Widening of sections toward the outside of the curve is not necessary. Widening of sections toward the inside of curves of under 2,400 feet radius shall be the larger of either 0.25 feet or 550/radius in feet.

Appendix 3.D: High-Speed Equipment Only, Structure Gauge and Fixed Equipment Envelope, In Tunnels



In Tunnels		
Point ID	Horizontal Distance from TCL (feet)	Vertical Distance from TOR (feet)
Structure Gauge		
Walkway Side (See Appendix 3.C, Note 3)		
A	0.00	0.00
B	10.50	0.00
C	11.50	1.00
D	11.50	18.00
E	5.50	23.50
F	0.00	23.50
Non-Walkway Side		
A	0.00	0.00
L	-7.50	0.00
K	-10.00	3.00
J	-10.00	14.00
I	-8.75	18.00
H	-7.00	21.25
G	-3.75	23.50
F	0.00	23.50
Fixed Equipment Envelope		
Walkway Side (See Appendix 3.C, Notes 3 & 4)		
a	0.00	0.00
b	6.25	0.00
c	6.25	0.67
d	10.00	0.67
e	10.00	8.17
f	8.50	8.17
g	8.50	18.00
h	4.50	22.50
i	0.00	22.50
Non-Walkway Side		
a	0.00	0.00
o	-6.25	0.00
n	-8.50	4.00
m	-8.50	14.00
k	-7.50	18.00
j	-3.75	22.50
i	0.00	22.50

Notes:

1. See Appendix 3.C, Notes 1 through 6.
2. Corner shapes were set to clear a single track circular tunnel with a diameter of 28.50 feet and a two track tunnel with a center wall and a top arc radius of 24.00 feet as shown on the Tunnels Standard and Directive Drawings.

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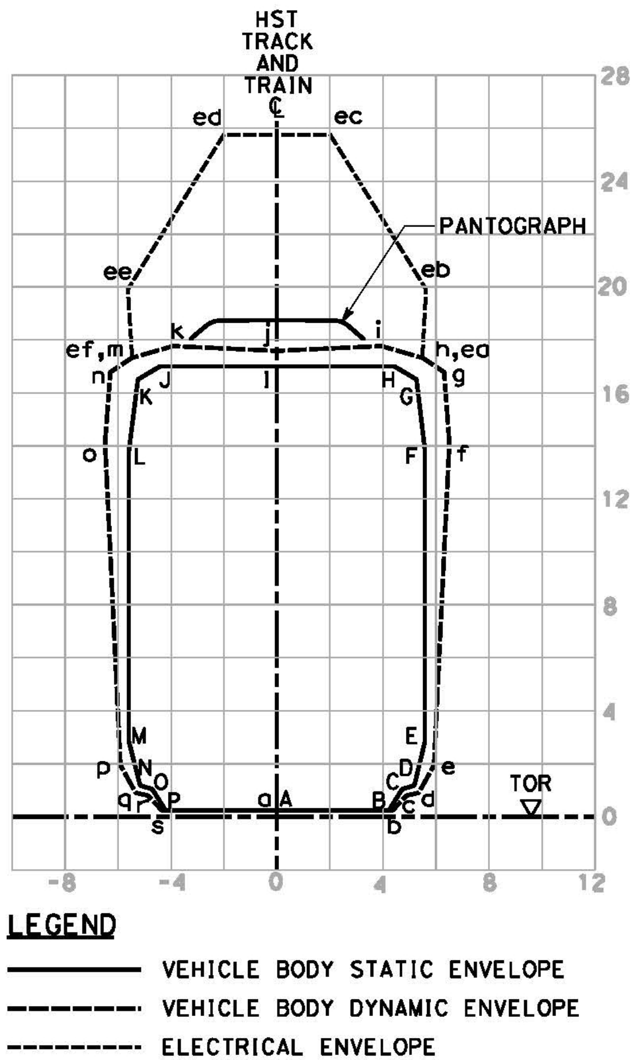
Appendix 3.E: All Passenger Equipment, Static Envelope and Dynamic Envelope, Tangent Track



Tangent Track		
Point ID	**Horizontal Distance from TCL (feet)**	**Vertical Distance from TOR (feet)**
Vehicle Body Static Envelope		
A	0.000	0.229
B, P	±4.208	0.229
C, O	±4.708	1.042
D, N	±5.167	1.167
E, M	±5.583	2.833
F, L	±5.583	13.833
G, K	±5.250	16.500
H, J	±4.417	17.000
I	0.000	17.000
Vehicle Body Dynamic Envelope		
a	0.00	0.229
b, s	±4.354	0.229
c, r	±4.875	0.792
d, q	±5.333	0.896
e, p	±5.917	1.927
f, o	±6.500	14.104
g, n	±6.292	16.792
h, m	±5.479	17.333
i, k	±3.938	17.771
j	0.000	17.583

Point ID	Horizontal Distance from TCL (feet)	Vertical Distance from TOR (feet) (See Note 6)	
		Open Sections	In Tunnels
Electrical Envelope			
ea, ef	±5.479	17.333	ea, ef
eb, ee	±5.625	19.917	eb, ee
ec, ed	±2.000	25.750	ec, ed

Notes:

1. Definition of the envelopes:
   a. The Vehicle Body Static Envelope defines the maximum shape and dimensions for any vehicle which may be operated on tracks that are shared with high speed passenger equipment.
   b. The Vehicle Body Dynamic Envelope takes the static envelope to the physical limits of motion under the maximum conceivable forces combined with the maximum allowable limits of wear and deficiencies including, for clearance purposes, motion due to track deficiencies and misalignments.
   c. The Pantograph is shown as it would be positioned with its center at its nominal elevation of 18.75 feet from TOR, see OCS Standard and Directive Drawings.
   d. The Electrical Envelope is the allowable space for overhead electrical equipment.
2. The Vehicle Body Static and Dynamic Envelopes are based on a combination of in-service high-speed passenger equipment, Amtrak's Bi-Level Passenger Car Clearance Diagram with the addition of roof mounted equipment on cab units, and Association of American Railroads (AAR) Plate F.

3. The Vehicle Body Static Envelope includes tolerances in the manufacture of the vehicle itself, but no allowances for any motion of the vehicle on the railroad or allowances for uneven wear of components.
4. The Vehicle Body Dynamic Envelope includes the vertical, lateral, and sway motion limits with the maximum allowable limits of wear and deficiencies such as deflated airbags and broken springs under the maximum conceivable forces. For purposes of defining clearances, this dynamic envelope also includes the effects of track conditions and alignment deviations.
5. The total movements assumed in the development of the Vehicle Body Dynamic Envelope are:
   a. Lateral expansion: 3.50 inches
   b. Downward expansion: 4.50 inches
   c. Upward expansion: 6.75 inches
   d. Angular movement: 3.00 degrees - rotated about centerline at a point 16.5 inches above TOR
6. The Electrical Envelope is lower in tunnel sections than in open air sections, however, the width is the same for both cases.
7. The width of the swept path of the vehicle body increases on curves due to mid-car and end-car overhang.
8. The width of the swept path of the vehicle body increase is determined by adding 550/radius (in feet) to the horizontal dimensions for points D, E, F, G, H, J, K, L, M, N, d, e, f, g, h, m, n, o, p, and q.
9. Points A, B, C, O, P, a, b, c, r, and s need not be shifted as they relate to components that are on the vehicle at or near the bogie positions or attached to the structure.
10. Widening may be neglected on tracks with radii of 10,000 feet or larger.
11. As an example, the increased dimensions for these points for a curve of 950 feet radius are given in the following table: (That radius is the internal radius of a standard No. 11 turnout.)

950 feet Radius					
Point ID	**Horizontal Distance from TCL (feet)**	**Vertical Distance from TOR (feet)**	**Point ID**	**Horizontal Distance from TCL (feet)**	**Vertical Distance from TOR (feet)**
Vehicle Body Static Envelope			**Vehicle Body Dynamic Envelope**		
A	0.000	0.229	a	0.000	0.229
B, P	±4.208	0.229	b, s	±4.354	0.229
C, O	±4.708	1.042	c, r	±4.875	0.792
D, N	±5.746	1.167	d, q	±5.912	0.896
E, M	±6.162	2.833	e, p	±6.496	1.927
F, L	±6.162	13.833	f, o	±7.079	14.104
G, K	±5.829	16.500	g, n	±6.871	16.792
H, J	±4.996	17.000	h, m	±6.058	17.333
I	0.000	17.000	i, k	±3.938	17.771
			j	0.000	17.583

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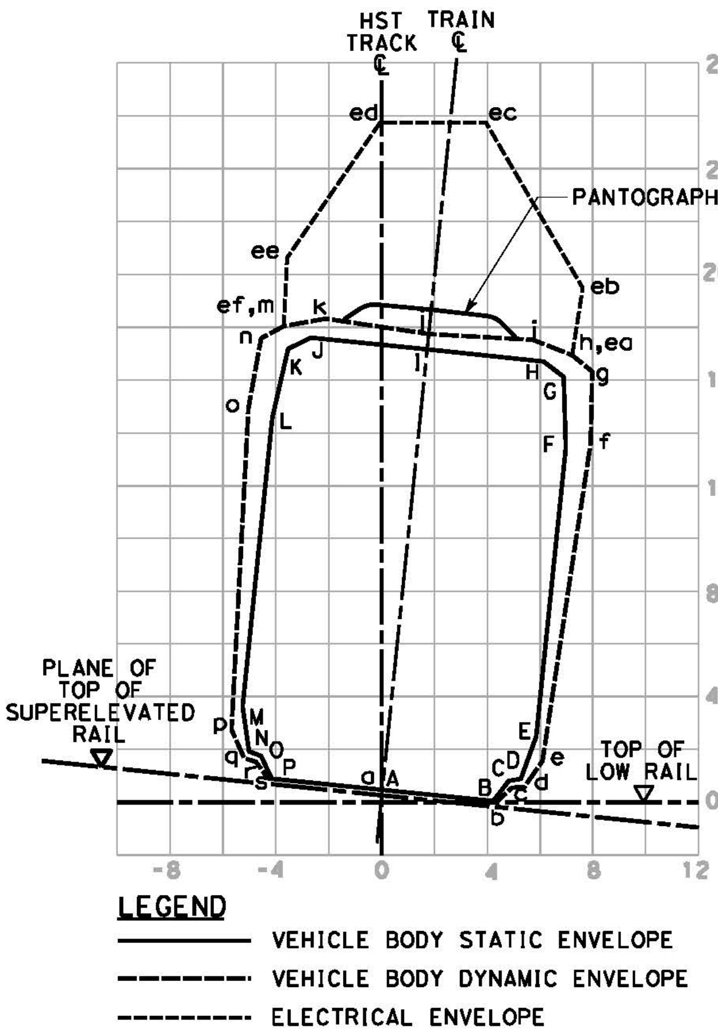
Appendix 3.F: All Passenger Equipment, Static Envelope and Dynamic Envelope Swept Path of Vehicle Rotated for Superelevation



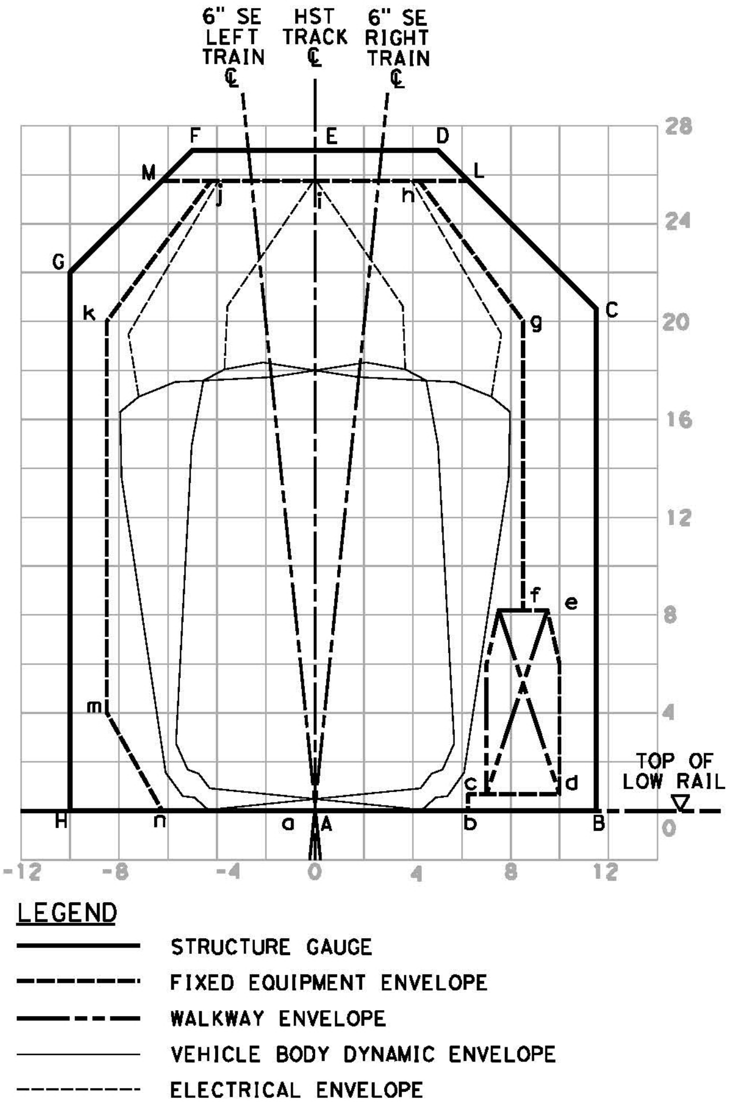
Point ID	Horizontal Distance from TCL (feet)	Vertical Distance from TOR (feet) (See Note 5)	
		Open Sections	In Tunnels
Electrical Envelope			
ea	7.211	16.934	16.934
eb	7.619	19.490	19.490
ec	3.950	25.750	24.250
ed	-0.050	25.750	24.250
ee	-3.576	20.624	20.624
ef	-3.691	18.039	18.039

Superelevated, No Widening (Values for 6 inches superelevation tabulated. See notes for method of calculation for other values.)		
Point ID	Horizontal Distance from TCL (feet)	Vertical Distance from TOR (feet)
Vehicle Body Static Envelope		
A	0.035	0.465
B	4.222	0.041
C	4.801	0.799
D	5.270	0.877
E	5.853	2.493
F	6.962	13.437
G	6.899	16.124
H	6.120	16.705
I	1.726	17.151
J	-2.668	17.596
K	-3.547	17.183
L	-4.148	14.563
M	-5.257	3.619
N	-5.011	1.919
O	-4.567	1.749
P	-4.152	0.890
Vehicle Body Dynamic Envelope (Without Increase in the Horizontal Dimension for the Effect of Small Radii)		
a	0.035	0.465
b	4.367	0.031
c	4.924	0.538
d	5.409	0.595
e	6.093	1.562
f	7.901	13.618
g	7.965	16.313
h	7.211	16.934
i	5.722	17.525
j	1.785	17.735
k	-2.113	18.319
m	-3.691	18.039
n	-4.554	17.582
o	-5.032	14.929
p	-5.680	2.755
q	-5.204	1.671
r	-4.758	1.521
s	-4.297	0.909

Notes:

1. The tables in this appendix give the position of points on the static and dynamic outlines of the vehicle rotated for 6 inches superelevation and without widening for the effects of curve radius. See the following notes for the method of calculation of the position of these points.
2. Determine the widened and rotated swept path of the vehicle as follows:
    a. Enlarge the width of the vehicle based on the radius of the curve. See Appendix 3.A notes 8, 9, and 10 for method of development of envelope due to curve radius.
    b. Determine the angle of rotation from the applied superelevation as follows: The angle of rotation is arcsin (superelevation/59.5 inches).
    c. Rotate the section by this angle about the point of rotation: The point of rotation for superelevation for both the static envelope and the dynamic envelope is the top inside corner of the inside rail of the curve, located at the track profile elevation and 28.25 inches (2.354 feet) offset from the track centerline.
3. The angle is 5.78756 degrees, or 5 deg 47 min 15 sec for 6 inches superelevation.
4. Points ec and ed do not rotate. They shift laterally a distance of 3.9 times the superelevation. For 6 inches superelevation, this distance is 23.4 inches or 1.95 feet.
5. The Electrical Envelope is lower in tunnel sections than in open air sections, however, the width is the same for both cases.
6. The Pantograph is shown as it would be positioned with its center at its nominal elevation of 18.75 feet, see OCS Standard and Directive Drawings.

Appendix 3.G: All Passenger Equipment, Structure Gauge and Fixed Equipment Envelope, Open Sections



Point ID	Horizontal Distance from TCL (feet)	Vertical Distance from TOR (feet)
Open Sections		
Structure Gauge		
Walkway Side (See Note 3 & 4)		
A	0.00	0.00
B	11.50	0.00
C	11.50	20.50
D	5.00	27.00
E	0.00	27.00
Non-Walkway Side		
A	0.00	0.00
H	-10.00	0.00
G	-10.00	20.50
F	-5.00	27.00
E	0.00	27.00
Under Existing Low Overhead Structures		
L	6.25	25.75
M	-6.25	25.75
Fixed Equipment Envelope		
Walkway Side (See Notes 1, 3, & 4)		
a	0.00	0.00
b	6.25	0.00
c	6.25	0.67
d	10.00	0.67
e	10.00	8.17
f	8.50	8.17
g	8.50	20.00
h	4.25	25.75
i	0.00	25.75
Non-Walkway Side		
a	0.00	0.00
n	-6.25	0.00
m	-8.50	4.00
k	-8.50	20.00
j	-4.25	25.75

Notes:

1. Definition of the envelopes:
   a. Structure Gauge defines the minimum distances from track to permanent features such as walls, columns and overhead structures.
   b. Fixed Equipment envelope defines the allowable space for fixtures such as signs, signals, lights, piping and conduits that will be attached to the permanent features defined under Structure Gauge.
   c. The walkway envelope defines a space sufficient for a person to be clear of any track mounted vehicle. The envelope illustrated is 7.50 feet high by 3.00 feet wide with the top 1.50 feet tapering to a width of 2.50 feet. Its precise location may vary depending upon local conditions. Therefore, the location of points b, c, d, e, and f will vary with the location of the walkway.
2. The Dynamic Envelopes for 6 inches superelevation each way are shown to illustrate their fit within the Structure Gauge and Fixed Equipment Envelope. See Appendix 3.F for dimensions of these envelopes.

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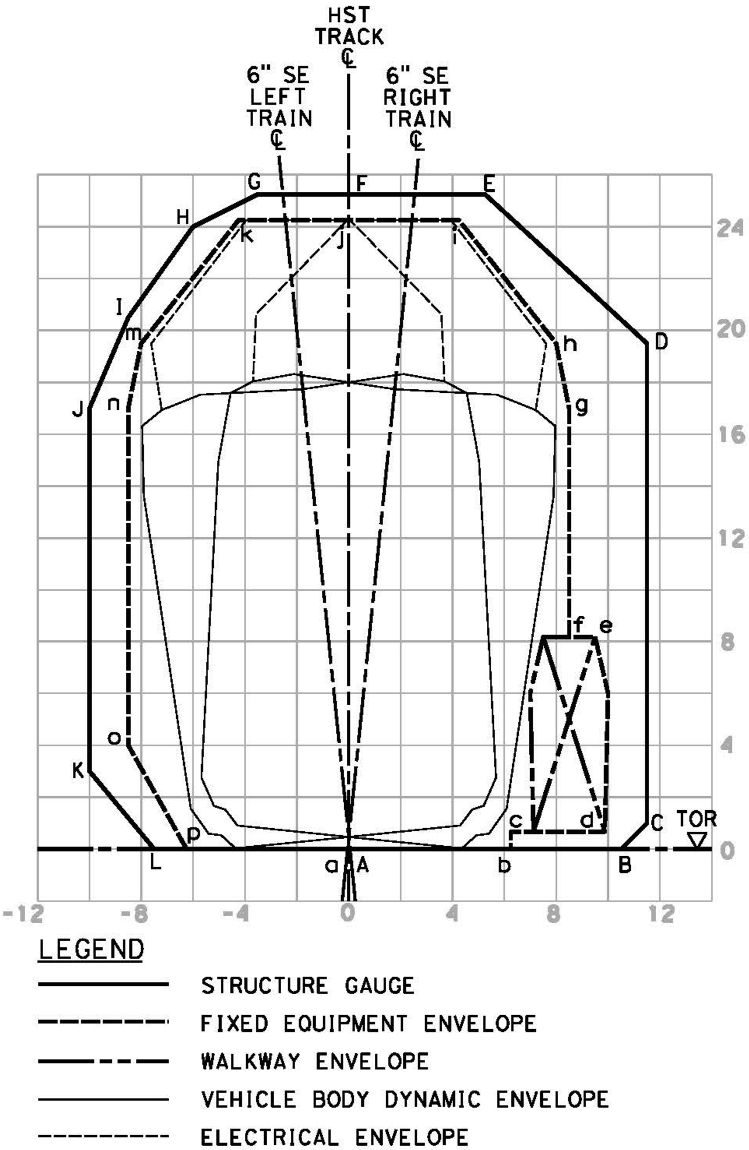
3. Right side dimensions in the figure and table are those that apply to the walkway side regardless of the actual location of the walkway. Left side dimensions in the figure and table are those that apply to the non-walkway side regardless of the actual location of the walkway.
4. Offset to structure on walkway side shall be 12.50 feet or niches shall be provided as required for placement of larger equipment.
5. Structure shall provide sufficient clear distance below TOR for the track form, under track equipment and other fixtures that must pass under the tracks.
6. Widening of sections toward the outside of the curve is not necessary. Widening of sections toward the inside of curves of under 2,400 feet radius shall be the larger of either 0.25 feet or 550/radius in feet.

Appendix 3.H: All Passenger Equipment, Structure Gauge and Fixed Equipment Envelope, In Tunnels



In Tunnels		
Point ID	Horizontal Distance from TCL (feet)	Vertical Distance from TOR (feet)
Structure Gauge		
Walkway Side (See Appendix 3.G, Note 3)		
A	0.00	0.00
B	10.50	0.00
C	11.50	1.00
D	11.50	19.50
E	5.25	25.25
F	0.00	25.25
Non-Walkway Side		
A	0.00	0.00
L	-7.50	0.00
K	-10.00	3.00
J	-10.00	17.00
I	-8.50	20.50
H	-6.00	24.00
G	-3.25	25.25
F	0.00	25.25
Fixed Equipment Envelope		
Walkway Side (See Appendix 3.G, Notes 3 & 4)		
a	0.00	0.00
b	6.25	0.00
c	6.25	0.67
d	10.00	0.67
e	10.00	8.17
f	8.50	8.17
g	8.50	17.00
h	8.00	19.50
i	4.25	24.25
j	0.00	24.25
Non-Walkway Side		
a	0.00	0.00
p	-6.25	0.00
o	-8.50	4.00
n	-8.50	17.00
m	-8.00	19.50
k	-4.25	24.25
j	0.00	24.25

Notes:

1. See Appendix 3.G, Notes 1 through 6.
2. Corner shapes were set to clear a single track circular tunnel with a diameter of 30.00 feet and a two track tunnel with a center wall and a top arc radius of 24.50 feet as shown on the Tunnels Standard and Directive Drawings.

Chapter 4

Track Geometry

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Revision	Date	Description
0	02 Mar 12	Initial Release, R0
0.1	Dec 2012	EXECUTION VERSION

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Acronyms

E / e	Equilibrium Superelevation
Ea	Actual Superelevation
Eu	Unbalanced Superelevation
HST	High-Speed Train
OCS	Overhead Contact System

4 Track Geometry

4.1 Scope

This chapter provides design criteria of geometric design requirements for mainline tracks, station tracks, yard tracks, turnouts, and crossovers on dedicated high-speed rail corridors of standard gauge (4’-8 ½”).

4.2 Regulations, Codes, Standards, and Guidelines

Refer to the *General* chapter for requirements pertaining to regulations, codes, and standards. Applicable codes and regulations include but are not limited to the following:

- Code of Federal Regulations (CFR) Title 49, Part 213, Track Safety Standards
- California Public Utilities Commission (CPUC) General Orders (GOs) 26D and 118
- American Railway Engineering and Maintenance-of-Way Association (AREMA) Manual for Railway Engineering

4.3 Types of Rail Corridors

4.3.1 Dedicated High-Speed Rail Corridors

Dedicated High-Speed Rail Corridors are segments of right of way within the High-Speed Train (HST) System where tracks are used exclusively for HST operations, designated as such in the operating rules and where the main tracks are physically separated from other railroad tracks. There is no operation of freight trains or other passenger trains within these corridors. The operation of trains and equipment used for Maintenance of Infrastructure work is permitted in these corridors.

4.3.2 Shared Corridors

Shared Corridors are segments along the HST System where the HST right of way is shared with other transportation system(s) including highway, freight or passenger rail.

Where HST tracks are shared with other passenger trains, design criteria for the maximum practicable design speed shall be used. At locations where tracks are shared with freight trains, the alignment standards for freight operations shall be checked and the more stringent criteria shall be applied.

4.4 Horizontal Alignment

Alignments for HST operation shall be designed to minimize the use of curves and to permit the maximum practical design speed.

When curves are used, the largest practical radii shall be used. Where the maximum design speed cannot be achieved, the highest achievable speed shall be used to define the geometry of the alignment.

The horizontal alignment shall be developed along track centerlines. It shall consist of tangents and circular curves connected by transition spirals of appropriate lengths.

When possible, double track alignment shall be designed with a constant distance in between track centerlines. Segments along straight line tracks shall be parallel and circular curves on adjacent, parallel tracks shall be concentric.

4.4.1 Selection of Design Speed

The speed to be used for the design of the alignment shall be the system design speed, not the operating speed, planned to be used at the time of start of operations. The purpose of determining design speed is to find the appropriate superelevation and spiral length for a particular curve in the alignment. The highest anticipated speed, superelevation, and unbalanced superelevation shall be used.

The maximum design speed for a curve shall be the same throughout the entire length of the curve from tangent points. Separate design speeds shall not be used for separate portions of a curve. If a speed limitation exists for any segment of the curve, then the design speed for the entire curve shall be the lower speed.

Refer to the *General* chapter for maximum allowed design and operating speeds.

4.4.2 Minimum Lengths of Alignment Segments

The minimum allowed segment length (L), in feet, shall be calculated by the following formula:

$$L = V \times 44/30 \times t$$

Where:

V = design speed (miles per hour)

t = attenuation time (seconds)

$t \geq$ 2.4 seconds (Recommended)

1.8 seconds (Minimum)

1.0 seconds (on diverging route of turnouts)

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Minimum segment lengths shall apply to horizontal and vertical alignment segments. The segment length requirement will govern only where other design considerations for the individual alignment elements do not require longer segment lengths.

Minimum segment lengths for various design speeds are presented in Table 4-1. Additional values, for design speeds not shown, can be obtained from the formula provided in this section, rounded up to the nearest integer.

Table 4-1: Minimum Segment Lengths at Various Speeds

Design Speed (miles per hour)	Minimum Segment Lengths (in feet) for times of		
	2.4 seconds	1.8 seconds	1.0 seconds
250	880	660	367
220	774	581	323
200	704	528	293
175	616	462	257
150	528	396	220
125	440	330	183
110	387	290	161
90	317	238	132

4.4.3 Minimum Radii

The minimum allowed curve radius shall be derived from the following formula:

$$R = 4V^2_{max} / (Ea + Eu)$$

Where:

R = Radius (feet)

V_{max} = Maximum design speed (miles per hour)

Ea = Actual superelevation (inches) Ea_{max}= 6 inches

Eu = Unbalanced superelevation (inches) Eu_{max}= 3 inches

Table 4-2 presents minimum values of curve radii for various design speeds. When possible, recommended values shall be used. Additional curve radii for design speeds not shown on Table 4-2 can be calculated with the formula provided above, using Ea= 6 inches for Minimum values and Ea= 3 inches as Recommended values. The minimum curve radius for tracks located outside the perimeter of the yards shall not be less than the value specified in Section 4.14.

Table 4-2: Recommended and Minimum Curve Radii

Design Speed (miles per hour)	Minimum Radius based on Superelevation Limits	
	Recommended (feet)	Minimum (feet)
250	45,000	28,000
220	35,000	22,000
200	30,000	18,000
175	22,000	14,000
150	16,000	10,000
125	10,500	7,000
110	8,100	5,400
90	5,500	3,600

4.4.4 Curves with Small Central Angles

For small central angles the radius shall be sufficiently large to provide the time-based minimum arc and spiral segment lengths. There is no limitation on maximum acceptable curve radius. In general, larger radii are preferable to smaller radii as the superelevation and unbalance values become smaller as radius increases. It is desirable that the radius selected results in the length of the simple curve portion being about equal to or longer than the length of spiral. Since each portion is an alignment segment, if each segment is equal in length, the entire curve with spirals should have a minimum length not less than three times the Minimum Segment Length for the design speed of the curve. Double (back-to-back) spirals or curves with long spirals and short arc lengths shall not be used.

4.4.5 Superelevation

Superelevation is the maximum difference in height between outer and inner rails on curved track, measured at the center of the rail head surface. Superelevation is used to counteract, or partially counteract, the centrifugal force acting radially outward on a train when it is traveling along the curve. A state of equilibrium is reached when the centrifugal force acting on a train is equal to the counteracting force pulling on a train by gravity along the superelevated plane of the track.

4.4.5.1 Equilibrium (Balanced) Superelevation

Equilibrium superelevation (E) may be derived by the simplified formula:

$$E = 4.0\ V^2 / R$$

Where:

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E = Equilibrium superelevation (inches)

V = Design speed (miles per hour)

R = Radius of curve (feet)

E is also expressed as:

E = Ea+Eu

Where*:*

Ea = actual superelevation (inches)

Eu = unbalanced superelevation (inches)

Thus: $E = (Ea+Eu) = 4.0\ V^2 / R$

4.4.5.2 Actual Superelevation

Actual superelevation (Ea) shall be accomplished by maintaining the top of the inside (or low) rail at the “top of rail profile” while raising the outside (or high) rail by the amount of the Ea. The inside rail is designated as the “grade rail” and the outside rail is designated as the “line rail”.

The Ea shall be determined to the nearest 1/4 inch by the formulas above. For any curve calculation on the main track which yields less than 1/4 inch of required superelevation, 1/4 inch shall be specified.

Curves within special trackwork shall not be superelevated. Yard tracks and other low speed tracks on which trains or equipment will normally be stationary for long periods shall not be superelevated. Yard lead tracks and other running tracks shall be superelevated as described in the discussion of those type tracks.

It is recommended that the Ea be limited to 6 inches.

4.4.5.3 Unbalanced Superelevation

Unbalanced superelevation (Eu), also referred to as cant deficiency, is the amount of superelevation not applied to the curve. Eu can also be defined as the difference between the equilibrium superelevation (E) and the Ea.

Eu=E-Ea

Where:

Ea = actual superelevation that is applied to the curve

Eu = unbalanced superelevation

The maximum Eu shall be limited to 3 inches.

4.4.5.4 Ride Quality and Superelevation

Ride quality on curves is determined by the amount of lateral acceleration which in curve design is expressed as Eu. Curves shall not be superelevated to balance the design speed, the calculated average speed, or the maximum operating speed. Eu values shall be kept between 1 and 3 inches for ride comfort and smooth running of the vehicles through curves.

- Minimum Eu shall be 1.0 inch, except where Ea+Eu is less than 2.0 inches, in which case Ea and Eu shall be set to be approximately equal.
- Maximum Eu shall be 3.0 inches, based on a lateral acceleration limit of 0.05g.

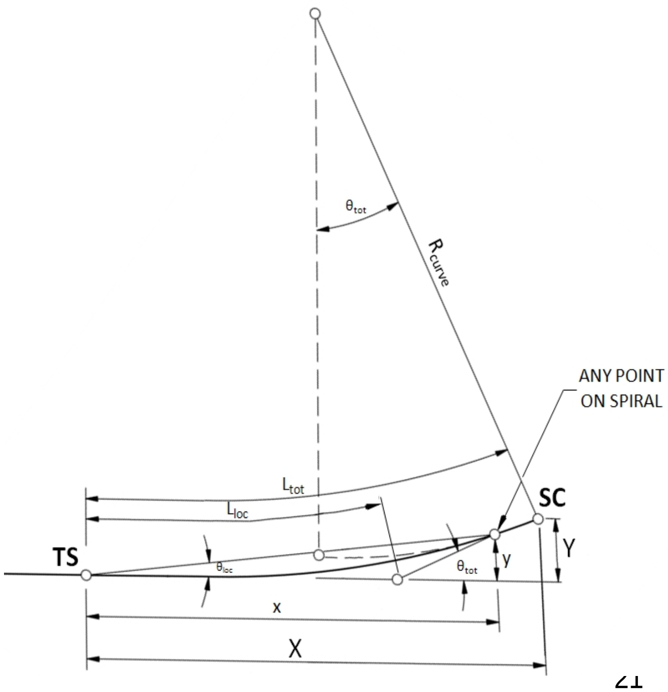
4.4.6 Spiral Curves

Spiral curves shall be used to transition from tangent tracks to tracks on circular curves and to gradually develop full track superelevation. Figure 4-1 illustrates the geometry of spiral transition curves.

Spiral transition curves used in high-speed track alignment shall be of the following types:

- Half-Sine spiral curves (variable rate transitions)
- Clothoid spiral curves (constant rate transitions)

Figure 4-1: Spiral Curves Definition



Where:

TS	Tangent Spiral point: the point of change from tangent to spiral
SC	Spiral Curve point: the point of change from spiral to circular curve
R_{curve}	Radius of circular curve, in feet
L_{loc}	Spiral length from TS to a specific location.
L_{tot}	Total length of spiral from TS to SC (or SCS) in feet
x =	Distance from TC point to any point on the curve, measured along the extended initial tangent
X=	Total x at the end of the transition curve from TS to SC
y=	Tangent offset distance to any point along the spiral, measured perpendicular to the extended initial tangent.
Y =	Tangent offset of the SC point.
θ_{loc} =	Spiral angle at any point along the spiral
θ_{tot} =	Total spiral angle

4.4.6.1 Half-Sine Spirals

Half-Sine spirals (also known as Sine Half-Wavelength Diminishing Tangent Curves) provide a variable rate of change in curvature between the tangent and circular curved track. Half-Sine spirals shall be used on:

- All curves along HST mainline tracks
- Curves having design speeds of 110 mph or more
- Curves associated with turnouts having design maximum speed of 110 mph or more

Half-Sine spirals are defined by the following formulas (angles in these formulae are in radians):

$$y=\frac{X^2}{R_{curve}}\left[\frac{\alpha^2}{4}-\frac{1}{2\pi^2}\left\{1-\cos\alpha\pi\right\}\right] \quad \alpha=\frac{x}{X}$$

$$R_{loc}=\frac{2R_{curve}}{\left[1-\cos\left(\pi\frac{L_{loc}}{L_{tot}}\right)\right]}$$

$$Ea_{loc}=0.5Ea_{curve}\left[1-\cos\left(\pi\frac{L_{loc}}{L_{tot}}\right)\right]$$

Where*:*

Ea_{loc}= Variable actual superelevation at a specific location along the spiral, in inches (Ea_{loc}=Ea_{curve} at the SC location)

Ea_{curve}= Actual superelevation at the SC and throughout the circular curve, in inches

4.4.6.2 Clothoid Spirals

Clothoid spirals provide a constant rate of change in curvature between the tangent and the connecting circular curve. Clothoid spirals shall be used on tracks having design speed lower than 110 mph. Clothoid spirals may be used on large radius curves that require small amounts or no superelevation and small unbalanced superelevation.

Clothoid spiral are defined by the following formulas:

$$\theta_{tot}=\frac{L_{loc}^2}{2R_{curve}L_{tot}}$$

$$R_{loc}=\frac{R_{curve}}{\left(\frac{L_{loc}}{L_{tot}}\right)}$$

$$Ea_{loc}=Ea_{curve}\left(\frac{L_{loc}}{L_{tot}}\right)$$

4.4.6.3 Spiral Lengths

The length of the spirals shall be the longest length determined by calculating the length requirements per Table 4-3. These lengths are the following:

- Length determined by allowed rate of change in superelevation, which controls the speed of car rotation around the track centerline (roll).
- Length determined by allowed rate of change in Eu, which controls the acceleration caused by centrifugal force not balanced by the Ea (lateral jerk).
- Length determined by limitation on twisting over the vehicle body.
- Length needed to achieve Attenuation Time

Table 4-3: Recommended and Minimum Length of Spiral (Ls)

Half-Sine (Variable Change) Spirals [1]		
Spiral Design Factor	**Recommended**	**Minimum**
Superelevation	1.63 Ea V	1.30 Ea V
Unbalance	2.10 Eu V	1.57 Eu V
Twist [2]	140 Ea	118 Ea
Minimum Segment	2.64 V	2.20 V
Clothoid (Linear Change) Spirals		
Superelevation	1.47 Ea V	1.17 Ea V
Unbalance	1.63 Eu V	1.22 Eu V
Twist	90 Ea	75 Ea
Minimum Segment	2.64 V	2.20 V

Notes:
[1] Longer lengths of half-sine spirals are due to the variability in the ramp rate.
[2] Provides maximum twist rates identical to the twist rate of the clothoids.
Where:
Ls= Spiral length (feet)
Ea = Actual elevation (inches)
Eu = Unbalanced elevation (inches)
V = maximum speed of the train (mph)

After calculation and selection of length, based on the governing requirement, the spiral length should then be rounded up to a convenient value for further calculation and use in the alignment.

4.4.6.4 Special Situations

Spirals on Large Radius Curves – Clothoid spirals may be used instead of half-sine spirals regardless of track type or design speed if the following conditions are met: The required superelevation and unbalanced superelevation are both under 1.0 inch at the maximum design speed; and the "Minimum Segment" length for the spiral is more than twice the length required by any other factor.

Spirals may be omitted if the following conditions are met:

- The required superelevation is zero (balancing superelevation for the maximum speed less than 0.5 inches); and
- The calculated offset of the curve due to application of the spiral is less than 0.05 feet in ballasted track or less than 0.02 feet in non-ballasted track.

Reverse Curves – Reverse curves shall only be allowed when there is insufficient distance between spiral curves to provide the minimum required length of tangent segment. In these cases, the spirals shall be extended to provide a reversing curve.

Compound Curves – Compound curves shall not be used on mainline tracks.

4.5 Vertical Alignment

The vertical alignment is defined as the top of rail profile grade. In curves with superelevation, the vertical alignment is the top of the low rail.

Vertical alignment shall be designed to have the smoothest practical profile while optimizing earthwork, structures, tunnels, and drainage. Use of multiple short grades and multiple changes in grade within any particular change of elevation (“sawtooth profiles”) shall be avoided to the extent practical. In addition to increasing operational costs and difficulty by requiring frequent changes in power, a line with multiple changes in grade is aesthetically unappealing. As a check on the reasonableness of the profile developed, it shall be drawn up at a highly condensed horizontal scale so that the vertical changes are exaggerated, otherwise, the alignment can appear deceptively smooth. Changes in top of rail profile gradients shall be connected by vertical curves.

4.5.1 Grades

Grades shall be as low as practical. In areas of relatively flat terrain, the grades should not exceed the recommended values per Table 4-4. In mountainous terrain, grades should be minimized in order to maximize operating efficiency which most often means lower gradients than the surrounding terrain.

The average grade over any 6.0 miles of line should not exceed 2.5 percent.

Maximum gradient shall not exceed 2.5 percent on ballasted track and 3.5 percent on non-ballasted track. When these limit values are used, the low end of the grade shall not be less than 2.0 miles beyond the end of a passenger station platform.

Maximum gradient through passenger station platform shall be 0.25 percent.

Minimum gradient through cuts, tunnels, and trenches shall be 0.25 percent.

Maximum segment length of continuous 3.5% grade shall not exceed 20,000 feet.

In areas occupied by turnouts and other special trackwork, grades up to 1.75 percent in ballasted track and 3.50 percent in non-ballasted track may be used where the use of lower grades would result in the requirement for lower speed turnouts.

For grade limitation at phase breaks, refer to the *Traction Power Supply System* chapter.

Table 4-4: Recommended and Maximum Grades

Track type and conditions	Recommended	Maximum
Ballasted	1.25%	2.50%
Non-ballasted	1.25%	3.50%
Ballasted track through turnouts and other special trackwork	0.50%	1.75%
Non-ballasted track through turnouts and other special trackwork	1.25%	3.50%
Mainline tracks through Station Platforms	0%	0.25%

4.5.2 Vertical Curves

Vertical Curves shall be Parabolic. The length of vertical curves shall be rounded up to nearest 100-foot increment where practical.

4.5.2.1 Vertical Curve Acceleration Rates

The acceleration value to be used for vertical curves shall not exceed 0.90 ft/sec^2.

4.5.2.2 Minimum Vertical Curve Lengths (L_{VC})

The minimum vertical curve lengths (L_{VC}), in feet, on lines carrying HSTs only shall be the longer of the following:

L_{VC}= 3.5 V or L_{VC} = 2.15 V^2 (Δ%/100) / 0.90 ft/sec^2, but not less than 200 Δ %

Where:

V = Design speed (miles per hour)

Δ% = algebraic difference of the gradients (in %)

4.5.2.3 Vertical Curves in Shared Corridors

Where HST tracks closely parallel lines for other passenger or freight trains such that a common profile is desirable, the longest vertical curve length determined by separate calculation for each type of traffic shall determine the vertical curve length to be used for all tracks. The length of vertical curve for the other systems shall be based on the standards of the systems involved.

4.6 Combined Horizontal and Vertical Curves

Horizontal and vertical curves may overlap. It is preferred to avoid overlap of vertical curves and spiral curves. Overlaps may be used if this consideration causes an increase in cost, increases the height of fill or aerial structures, or results in other aspects of the alignment being reduced below recommended values.

4.7 High-Speed Turnouts (60 mph and faster)

Turnout geometries are presented for the following speeds: 60 mph, 80, mph, 110 mph, and 150 mph. The requirements of this section are limited to geometric considerations only. The location and nature of operating mechanisms, track components, and so forth are found in the *Trackwork c*hapter. Other spatial considerations, including distance between track centers and space beside and around turnouts can be found in the *Trackway Clearances* chapter.

High-speed turnout and crossover designs are based on the following criteria:

- Eu not to exceed 3 inches
- Minimum time over any turnout segment or curve connected to a turnout, including spirals on the frog end of turnouts and spirals into a curve on the diverging track that is adjacent to the turnout, about 1.0 second
- Maximum Virtual Transition Rate at switch point: 4.5 inches/second
- Ratio of entry radius to turnout body radius: Not less than 2:1.
- Curved frogs
- Spirals shall be kept out of frogs

Figure 4-2: High-Speed Turnouts

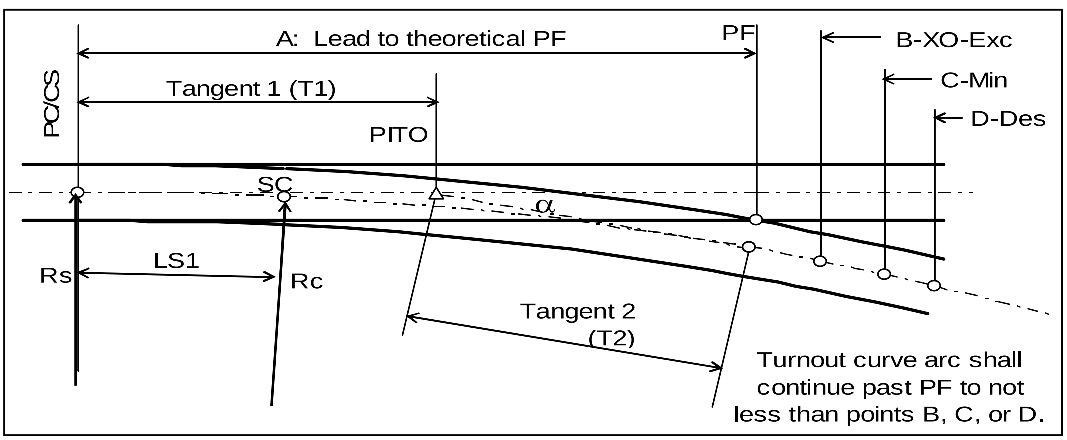


Table 4-5: High-Speed Turnouts

Geometry of Turnout and its Segments, in feet unless stated otherwise				
Design Speed	60 mph	80 mph	110 mph	150 mph
Turnout Entry Radius	10,000.00	18,000.00	34,000.00	80,000.00
Turnout Body Radius	5,000.00	9,000.00	17,000.00	32,000.00
Switch Spiral Length and Desirable Frog End Spiral Length	90.00	120.00	160.00	220.00
A. Distance to Theoretical Point of Frog (Zero Point, also called Fine Point)	237.53	318.53	436.76	610.07
Angle at Theoretical Point of Frog	2d27m49s	1d 50m12s	1d20m14s	0d58m27s
Derived Frog Number (AREMA method)	23.25	31.2	42.8	58.8
Tangent 1 (T1)	128.06	171.67	333.14	461.99
Tangent 2 (T2)	109.48	146.87	276.93	363.30
Turnout Body Curve Arc Length, SC to PF	147.50	198.51	276.74	375.18
B. Distance to point of 5.85 ft. separation	262.62	352.18	482.98	673.52
C. Distance to point of 7.00 ft. separation	285.48	382.85	525.11	731.34
D. Distance to point of 8.00 ft. separation	303.85	407.49	558.97	777.81

Notes: Values in table are for illustration purposes, and so are generally given to 2 decimal places. This is not to be construed as the necessary limit for the alignment calculations.

Placement of high-speed turnouts in relation to each other and to horizontal alignment features shall be based on 1.0 seconds of run time of the slower alignment element, whether another turnout or the end of a spiral.

4.8 Low and Medium Speed Turnouts (50 mph and slower)

Turnouts to storage and refuge tracks, yard connection tracks, and within yards and any other low and medium speed locations shall use AREMA standard frogs. The standard turnout sizes to be used shall be Numbers: 9, 11, 15, and 20.

Number 11 turnouts shall be used as the standard yard turnout, and as the minimum size turnout to be installed in main tracks with speeds of 125 mph or less and in station tracks. Yard Lead or other tracks shall be no less than Number 20 turnouts if the conditions allow it. Number 9 turnouts may be used where geometric constrains make the use of Number 11 turnout impractical.

Figure 4-3: Low and Medium Speed Turnouts

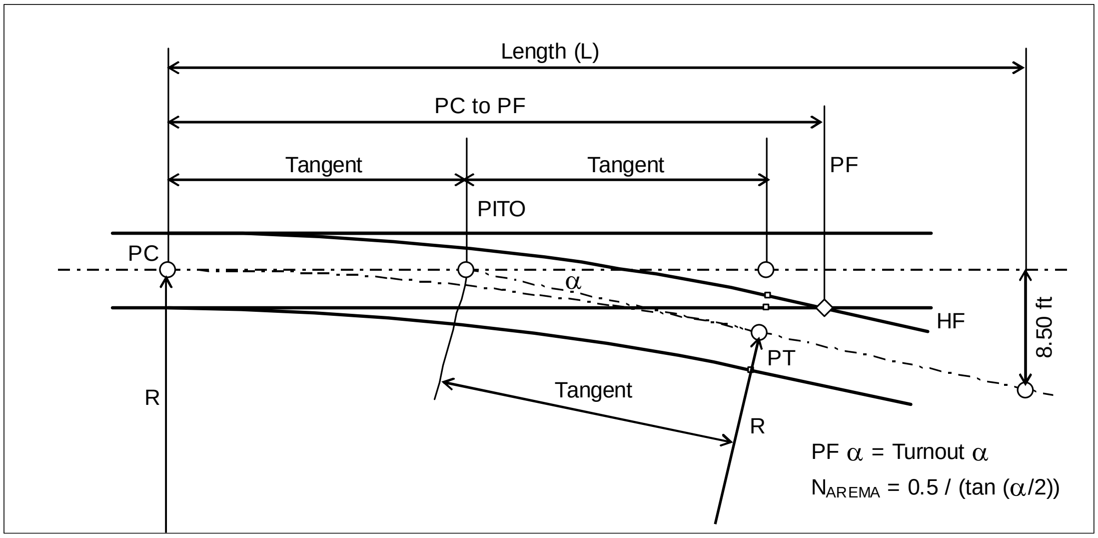


Table 4-6: Low and Medium Speed Turnouts

Number	9	11	15	20
Defined Angle (degrees/minutes/seconds)	6d21m35s	5d12m18s	3d49m06s	2d51m51s
Radius	620 feet	950 feet	1750 feet	3275 feet
Tangent	34.44 feet	43.18 feet	58.33 feet	81.87 feet
Lead, PC to ½ inch PF	77.19 feet	95.43 feet	129.58 feet	176.87 feet
PC to 8.5 feet separation	110.71 feet	136.49 feet	185.69 feet	251.77 feet
Tangent Rail, ½ inch PF to Curve PT	8.31 feet	9.07 feet	12.92 feet	13.13 feet
Maximum Diverging Speed	20 mph	25 mph	35 mph	50 mph
Unbalance at Maximum Diverging Speed	2.58 inches	2.63 inches	2.80 inches	3.05 inches

Notes: Values in table are for illustration purposes and so are generally given to 2 decimal places. This is not to be construed as the necessary limit for the alignment calculations.

The switch points of these turnouts will be cut back slightly from the PC location shown. The exact shape and cutback of the switch point is found in *Trackwork* chapter. Spatial considerations, including space beside and around turnouts can be found in the *Trackway Clearances* chapter.

Run time considerations are not relevant to the location and spacing of low and medium speed turnouts. Vehicle twist and relative end offsets are the controlling factors. It is recommended to provide at least 75.00 feet of straight track in advance of a switch. Where practical, these turnouts shall be spaced so that the length between turnouts is at least equal to the sum of

vehicle truck centers plus one end overhang. Where the usage of switches that are point to point is such that trains are unlikely to use both turnouts, the switch points may be placed closer, down to 30 feet apart. It is desirable that the track off the frog end of the turnout be straight to at least the end of the switch tie set, which may be taken as the point at which the tracks are 8.50 feet apart. In the development of crossovers, track ladders, and track fans, it will be seen that these values are not always achievable.

4.9 Non-Standard Turnouts

Turnouts on curves or in locations where standard turnouts cannot be used shall be designed as special cases. These turnouts shall be designed such that the lateral forces and rates of change in these forces are similar to those in standard design turnouts.

For all turnouts, the Eu shall not exceed 3.0 inches on either side of the turnout.

For high-speed turnouts, the following governs:

- Switch end spiral having a transition rate not more than 4.5 inches per second
- Eu at the point of switch: 1.5 inches
- If the curve does not continue beyond the turnout on the frog end, a frog end spiral having a transition rate of not more than 4.5 inches per second shall be applied.
- Minimum time over any turnout segment or curve connected to a turnout shall be approximately 1.0 second, and not less than 0.9 seconds.

For low and medium speed turnouts, compound internal curves shall not be used. If a curved frog is used, the end of the curve shall be outside the casting portion of the frog.

4.10 High-Speed Crossovers

Crossovers in high-speed turnouts are more complex, as the curve continues through the frog. In order to place crossovers for 60 mph or faster between tracks at the standard track center spacing of 16.50 feet, the frog end spiral must be shortened to keep the spiral out of the frog. The length of the 2 spirals combined achieves the minimum 1.0 second run time when they are considered as 1 design element. Figure 4-4 shows the normal relationship between crossover components in a crossover between 16.50 feet track centers.

Figure 4-4: High-Speed Crossovers

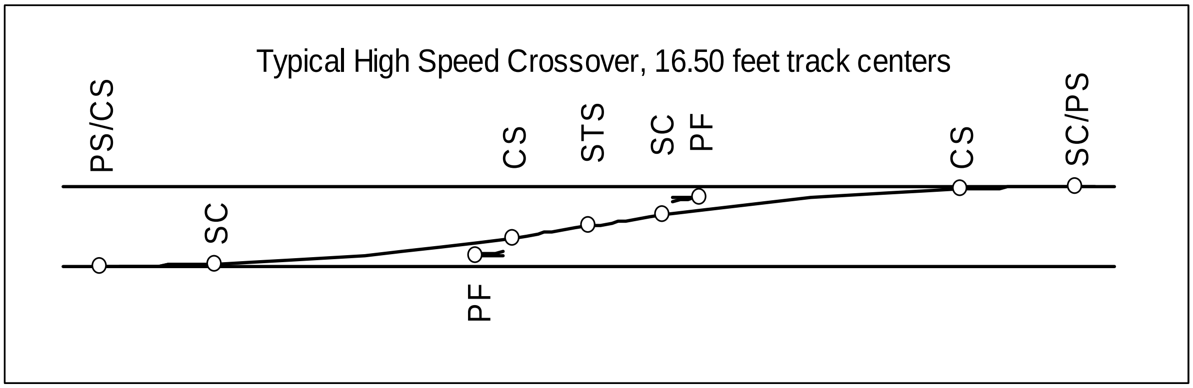


Table 4-7: High-Speed Crossovers – 16.50 feet Track Centers

Geometry of Turnout and its Segments, in feet unless stated otherwise				
Design Speed	60 mph	80 mph	110 mph	150 mph
Track Centers	16.50	16.50	16.50	16.50
Total Length along main track	618.74	829.97	1,138.63	1,583.92
Total Length along Crossover Track	619.05	830.20	1,138.80	1,584.04
Turnout Entry Radius	10,000.00	18,000.00	34,000.00	80,000.00
Turnout Body Radius	5,000.00	9,000.00	17,000.00	32,000.00
Switch Spiral Length	90.00	120.00	160.00	220.00
Frog Spiral Length	45.00	62.00	85.00	115.00
Angle at STS	3d01m31s	2d 15m15s	1d38m28s	1d11m49s
Length of Entry Curve	0.00	0.00	0.00	0.00
Length of Turnout Body Curve	173.52	233.10	324.40	457.02

Notes: Values in table are for illustration purposes and so are generally given to 2 decimal places. This is not to be construed as the necessary limit for the alignment calculations.

For high-speed crossovers between track centers of between 16.50 feet and 21.50 feet, longer spirals between turnouts may be used, but with the limitation that they be kept out of the frog. Where the track centers are 21.50 feet or greater, a full length spiral shall be used. High-speed crossovers shall not be used between tracks having track centers of under 16.50. For other spatial requirements see the *Trackway Clearances* chapter.

4.11 Low and Medium Speed Crossovers

The essence of a crossover is 2 turnouts connected at their frog ends. This occurrence is common. The distance of concern in crossovers is the central tangent, shown as “Tangent” in Figure 4-5. For close track centers and small turnout numbers, this distance can be less than the truck centers plus one end overhang that is the minimum tangent distance between reversing curves.

Figure 4-5: Low and Medium Speed Crossovers

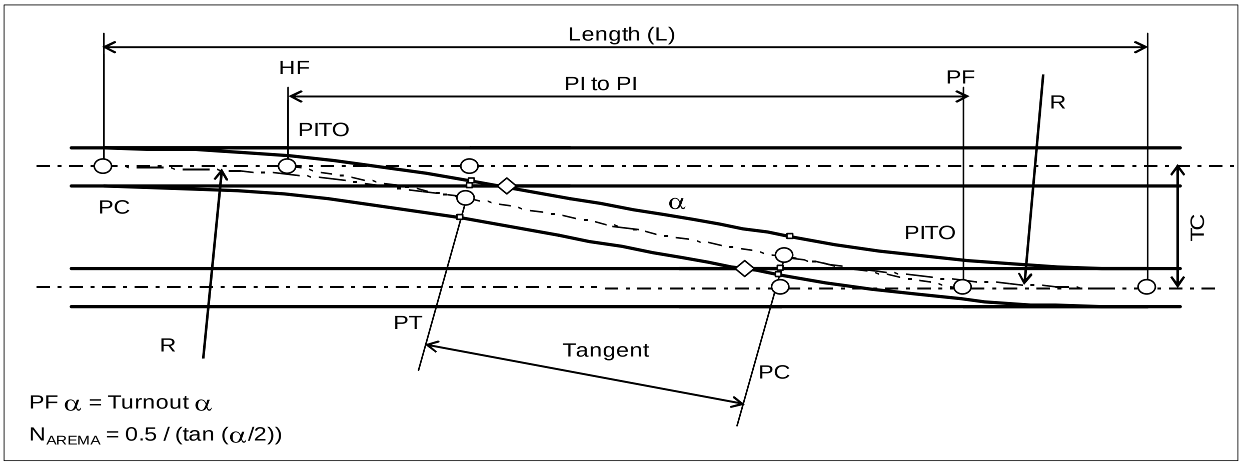


Table 4-8: Low and Medium Speed Crossovers

Number	9	11	15	20
Defined Angle	6d21m35s	5d12m18s	3d49m06s	2d51m51s
Radius	620 feet	950 feet	1750 feet	3275 feet
Allowed Speed	20 mph	25 mph	35 mph	50 mph
Length (L) end to end of crossover, 15.00 feet track centers	203.47 feet	251.02 feet	341.42 feet	463.56 feet
PITO to PITO distance on tangent, 15.00 feet track centers	134.58 feet	164.66 feet	224.75 feet	299.82 feet
Change in length per 1.00 foot change in track centers, either of the above	8.972 feet	10.978 feet	14.983 feet	19.988 feet
Tangent length on diagonal, 15.00 feet track centers	66.53 feet	78.98 feet	108.58 feet	136.44 feet
Change in length per 1.00 foot change in track centers	9.03 feet	11.02 feet	15.02 feet	20.01 feet

Notes: Values in table are for illustration purposes and so are generally given to 2 decimal places. This is not to be construed as the necessary limit for the alignment calculations.

Since small radii curves in turnouts result in short component life and working the equipment to near its limits of movement is undesirable, it is recommended that the turnouts in crossover be Number 11 or larger. It is also recommended to keep the track centers at 15.00 feet or larger for this and other reasons.

4.12 Double Crossovers (Scissors Crossovers)

Where space is constrained and crossovers allowing universal moves are desired, crossovers may be overlapped to form a double crossover. This form of crossover is sometimes called a scissors crossover, as on some systems the term “double crossover” means two single crossovers of opposite hand placed in succession.

Double (scissors) crossovers shall be used only where their use keeps other aspects of the alignment from being reduced to less than minimum values due to their high cost and maintenance requirements. Double crossovers using high-speed turnouts shall not be used unless the track centers are wide enough that the crossing diamond may be straight, and preferably where the crossing angle is equal to or less than that in a Number 15 double crossover.

The following double crossovers may be used:

- Number 9 (Shall not be used in main tracks)
- Number 11 at 15.00 feet or larger track centers (Shall not be used in main tracks)
- Number 15 at 15.00 feet or larger track centers

Double (scissors) crossovers with frog angles larger than that of a Number 15 turnout require movable center frogs, and therefore should be used only where use of smaller crossovers affects run time.

4.13 Track Layout along Station Platforms

Tracks along passenger platforms shall be of sufficient length to avoid delay of through trains by trains making the station stop. Turnouts connecting the platform track with the main track shall permit speeds not less than the train would be running if decelerating to or accelerating from the station stop. Other than the main line turnouts, the normal train operation into or out of the platform shall not pass through the curved side of turnouts.

Platform tracks shall be tangent through the platform length and to a distance of not less than 75 feet beyond the ends of the platform~~.~~ If the platform track must be curved, the largest practical radius of curve shall be used, and other means used to provide for accessibility in accordance with Americans with Disabilities Act (ADA) requirements.

Other tracks connected to platform tracks shall turn out of the tangent portion of the platform tracks. Turnouts shall be placed not less than 75 feet beyond the ends of the platform.

See Standard Drawings for Typical Station Connection Tracks Layouts.

Figure 4-6: Detail of Station Entry/Exit High-Speed Turnout and Return Curve

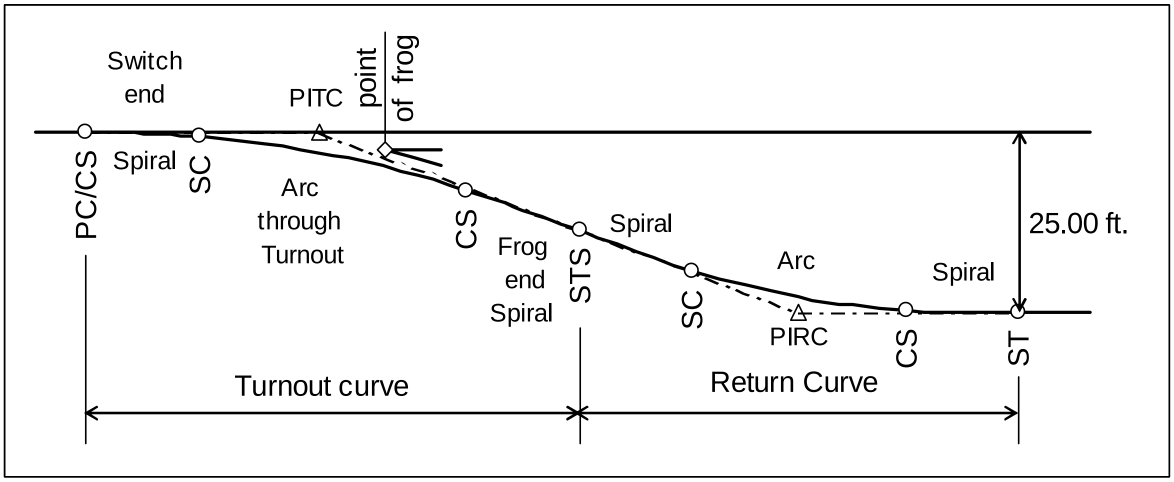


Table 4-9: Geometry of Station Entry/Exit High-Speed Turnouts and Return Curves

Geometry of Connection and its Segments, in feet unless stated otherwise			
Design Speed	60 mph	80 mph	110 mph
Platform Track Offset	25.00	25.00	25.00
Turnout Entry Radius	10,000.00	18,000.00	34,000.00
Turnout Body Radius	5,000.00	9,000.00	17,000.00
Switch Spiral Length	90.00	120.00	160.00
Frog Spiral Length	90.00	120.00	160.00
Return Curve Radius	4,000.00	7,000.00	13,500.00
Curve Spiral Length	90.00	120.00	160.00
Total Length along main track	743.65	991.80	1,364.60
Total Length along Platform Track	744.25	992.25	1,364.92
Angle at STS	3d44m07s	2d 48m04s	2d02m17s
Length of Entry Curve	0.000	0.000	0.000
Length of Turnout Body Curve	213.47	290.02	404.71
Length of Return Curve	170.78	222.24	320.21

Notes: Values in table are for illustration purposes and so are generally given to 2 decimal places. This is not to be construed as the necessary limit for the alignment calculations.

The turnouts for storage and refuge tracks at passenger stations will depend upon the operational requirements. Turnouts smaller than Number 11 shall not be used. Spirals need not be applied to the return curve for a stub end track. If the track is for yard access instead of to storage, a spiral appropriate to the design speed of the access track shall be applied.

4.14 Access Tracks to Yards and Maintenance Facilities

The criteria contained in this section are intended for the geometric design of tracks connecting the mainline to yards, Maintenance of Infrastructure (MOI), terminal layup and storage facilities. See section 4.13 for the geometric design of tracks connecting the mainline to station platforms.

Site constraints may lead to large distances between mainline access points and these facilities. For the purpose of minimizing time required to clear revenue tracks, these tracks shall be designed much like a secondary mainline railroad. The design speeds of the turnouts that are used between the mainline and these tracks shall be 60 mph. The design speed of crossovers between main tracks associated with these turnouts shall be 60 mph unless they also serve another purpose that requires a higher speed.

The minimum length between mainline turnout fouling point and the first yard or MOI turnout shall be not less than 1600 feet. The following are the minimum/maximum design parameters for these tracks

- Design speed: 60 mph, site conditions permitting. Where conditions do not permit 60 mph, a lower design speed may be used. This lower design speed shall be as high as site conditions permit.
- Minimum Curve Radii: 900 feet
- Maximum Actual Superelevation (E_a): 3 inches
- Maximum Unbalanced Superelevation (E_u): 3 inches
- Spiral Lengths (Clothoid): 62 feet per inch of superelevation or unbalanced superelevation, whichever gives the greatest length
- Minimum Length of Tangent between curves in the same direction: 0 feet. Compound curves must be joined by spirals of length equal to 62 feet per inch of change in superelevation or unbalance, whichever gives the greater length
- Minimum Length of Tangent between reversing curves. The length may be reduced by one-half the combined lengths of the adjacent spirals. $L_{min} = 9{,}400{,}000 / (R_1)^2 + 9{,}400{,}000 / (R_2)^2$, but not less than 40 feet
- Recommended Turnouts: not less than Number 15
- Minimum Turnouts: Number 11

- Minimum Track Centers, not including allowance for Overhead Contact System (OCS) poles, drainage, walkways, roadways, or other facilities that will be placed between tracks in some areas: 15.00 feet
- Minimum Track Centers on small radius curves may need to be larger than the values given above. If the following calculation results in a larger value, this value shall be used: 14.75 + 1,100 / Radius (in feet), but not less than 15.00 feet
- Maximum Grade: 2.50 percent
- Vertical Curves: 100 feet minimum length with a rate of change of not more than 1.00 percent per 100 feet

4.15 Yards Tracks

The specific track arrangement for each yard will depend upon the purpose of the yard and tracks in the yard. Therefore the basic layout will be determined by operational requirements. The requirements developed in this chapter are therefore limited to those of a general nature except for those relating to geometric constraints due to:

- Curvature related constraints due to vehicle characteristics
- Track length constraints due to train and individual vehicle length
- Profile and grade related issues

Other than the tracks connecting the yards to the revenue tracks, the design parameters for these tracks are speed-independent.

4.15.1 Connecting and Switching Tracks Inside Yards

The following standards apply to tracks on which trains will not be stored or left standing but are installed for the purpose of connections between yard tracks and yard access tracks within the area designated as yards, all types, and other low speed tracks.

- Minimum Curve Radii: 620 feet
- Minimum Length of Tangent between curves in the same direction: 0 feet (compound curve)
- Minimum Length of Tangent between reversing curves: $L_{min} = 9{,}400{,}000 / (R_1)^2 + 9{,}400{,}000 / (R_2)^2$, but not less than 40 feet.
- Minimum Turnout Number: 9 (internal radius 620 feet). If in a track with high volume traffic, the minimum shall be a Number 11.
- Minimum Track Centers: 15.00 feet

Wider track centers shall be provided if OCS poles, light poles, drainage, signal masts, equipment cases, walkways, service aisles or other facilities are to be placed between tracks.

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Minimum Track Centers on small radius curves shall be increased if the following calculation results in a larger value: 14.75 + 1,100 / Radius (in feet), but not less than 15.00 feet. This value does not include allowance for OCS poles, drainage, walkways, roadways, or other facilities that will be located between tracks.

- Maximum Grade: 2.50 percent
- Minimum Length of Vertical Curve: 50 feet with a rate of change of not more than 2.00 percent per 100 feet.

For additional criteria on walkways and service aisles see *Civil* chapter.

4.15.2 Servicing and Storage Tracks

The following standards apply to those portions of tracks on which trains or equipment will be left standing, serviced, or stored and do not apply on the approach portions of those tracks. These standards apply only to the usable length of track and any overrun distances or, in the case of stub end tracks, the portion between usable length and the bumping post or other end of track device.

- Usable Length of Track – The usable length of track is defined as the length of track which is usable for its defined purpose. Usable length does not include space for bumping posts or other end of track devices, defined set back from the end of track device, defined set back from signals, space occupied by road crossings, turnouts to other tracks, and any other feature that render the equipment on the track inaccessible to service, if the purpose of the track is to hold equipment while being serviced, or unusable for storage if the purpose of the track is to store passenger trains or other equipment.

  Usable length of track for train servicing and storage tracks is defined based on the maximum potential train length. Sufficient length beyond train length to hold a switch engine shall also be provided. Minimum length shall be 1400 feet.

  Usable length of track for other purposes: For tracks not intended to hold full length trains, the usable length shall be defined by the length of equipment that it is intended to hold plus some allowance for placement of equipment, and desirably additional length sufficient to hold a switch engine. Minimum length shall be 75 feet plus the length to be occupied by equipment.

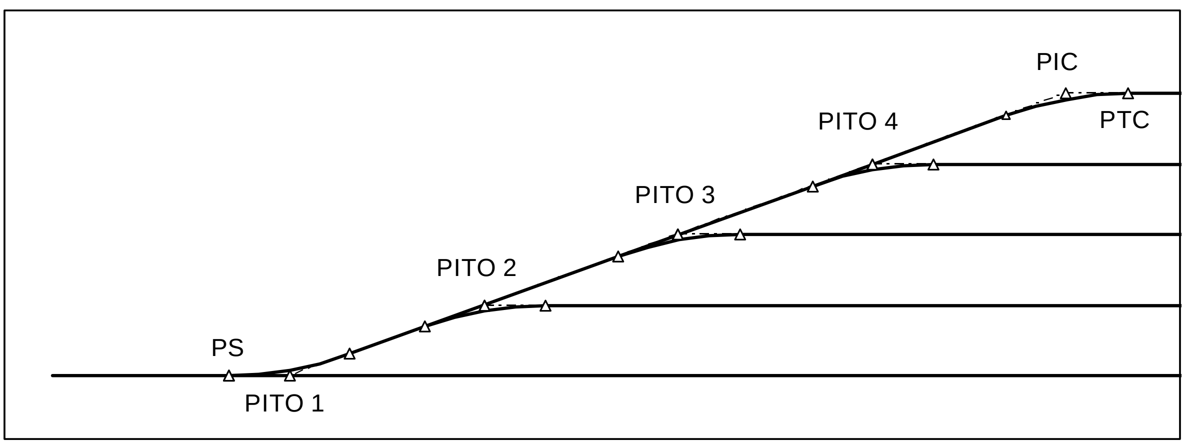
- Minimum Curve Radii for curves within the usable length – 10,000 feet
- Minimum Grade within the usable length – between 0.00 percent and 0.20 percent or between 0.30 percent and 0.50 percent down from the access point. In the case of double ended tracks, the low end access track shall not be lower than the highest point within the portion designated as usable length.
- Minimum Length of Vertical Curves – 50 feet minimum length with a rate of change of not more than 1.00 percent per 100 feet.

- Minimum Track Centers, between tracks on which servicing of equipment will be performed – alternating spacing of 28.00 feet and 20.00 feet. These track centers provide space between tracks for roadways on the wider centers and cart paths or walkways on the narrower centers. However, these do not include allowances for OCS poles, light poles, drainage, signal masts, electrical cases, inspection platforms and pits, or other facilities that may interfere with the use of the aisles as traveled ways. Wider track centers shall be provided where these facilities are needed.
- Minimum Track Centers, between tracks on which no servicing of equipment will be performed – 15.00 feet. Wider track centers shall be provided if OCS poles, light poles, drainage, signal masts, electrical cases, major walkways or other facilities must be placed between tracks.

4.15.3 Simple Track Ladders

A track ladder is a series of turnouts used to connect a group of parallel tracks to each other in conjunction with either an approach track or a stub end track to permit equipment to be accessed or shuttled between tracks. The most common form of connection of multiple parallel tracks is a straight ladder, also called a simple ladder. A simple ladder is a series of turnout connected end to end so as to access all the parallel tracks. Its primary advantage is its simplicity in design, construction and maintenance. Its disadvantage is its length when more than a few tracks are involved.

Figure 4-7: Simple Ladder (4 Tracks Illustrated)



Calculation of the points on these ladders is straightforward. The Point of Switch (PS) to Point of Intersection of the Turnout (PITO) 1 dimension is a property of the turnout used. The PITO 1 to PITO 2 and PITO 2 to PITO 3 and so forth lengths parallel to the tracks are simply track spacing divided by the tangent of the frog angle of the turnout. PI to PI lengths along the ladder track are track spacing divided by the sine of the frog angle of the turnout. When summed and the length of the final curve tangent added, the length of the entire ladder is determined.

Dimensions for the basic ladder connecting tracks at 15.00 centers using Number 11 turnouts are as follows:

- Between PITOs parallel to the lead track: 164.66 feet
- Between PITOs on the ladder track: 165.34 feet
- Total distance, PS entry turnout to curve PT for the case illustrated: 745.01 feet
- Total PS to PS distance for double ended tracks with 1,500 feet clear length: 2,990 feet
- Length utilized by ladder for each additional track: 329.33 feet

When more than a few tracks are involved, the total length of this arrangement quickly becomes impractical, particularly where track centers are large. Thus, the need for compound ladders to shorten the overall yard length.

4.15.4 Double Angle Track Ladders

Considerable space can be saved by use of double angle ladder tracks, as the larger angle considerably reduces the length required to achieve the required offsets. The following is provided for assistance in understanding the design of multi-track ladder tracks.

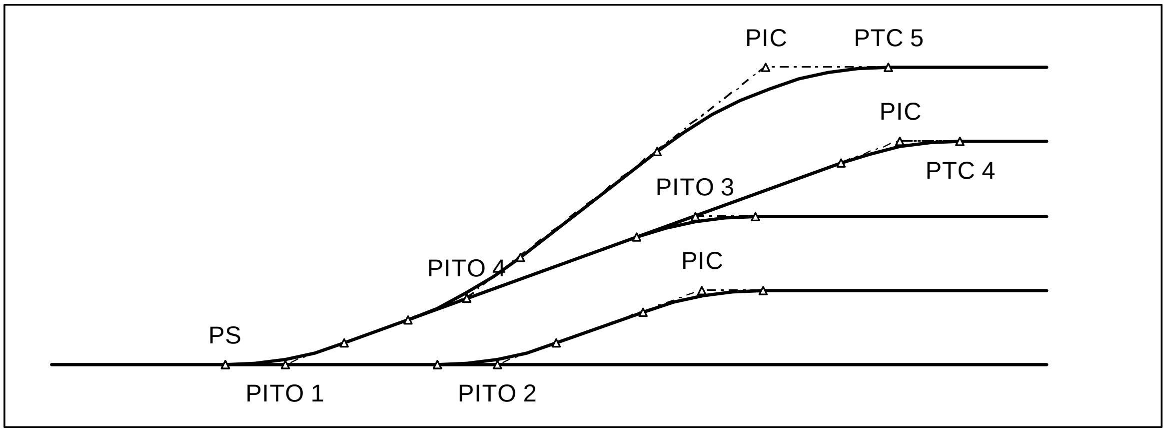
First, look at the situation with the same number and spacing of tracks as used in the simple ladder illustration. The single frog angle ladder using Number 11 turnouts and 15.00 feet track centers was 745 feet long from first point of switch to the point of development of the full width. By taking only one track off the outside, the length is reduced to approximately 580 feet, a saving in length of over 320 feet if the yard is double ended.

This method can be carried forward with additional tracks to whatever extent is necessary. The greater the number of tracks, the greater is the saving in length. For the illustrated six diverging track arrangement, the length from beginning point to end of last curve is about 734 feet, using Number 11 turnouts. The same number of tracks using a simple ladder would utilize approximately 1074 feet. Thus, for a double ended arrangement, the length saving is 680 feet.

The greater the number of tracks, the greater is the savings in overall yard length. For large numbers of tracks, the arrangement can be carried at least one step further to go to a triple ladder. Figure 4-8 and Figure 4-9 illustrate the nature of these savings.

When developing this form of track arrangement, the need to provide space for switch machines must not be overlooked. In addition, with these more complex track ladder arrangements, consideration must be given to the location of OCS poles since complex track layouts equate to complex overhead wiring layouts, including the need for wire termination poles and downguys.

Figure 4-8: Double Ladder (4 Diverging Tracks Illustrated)

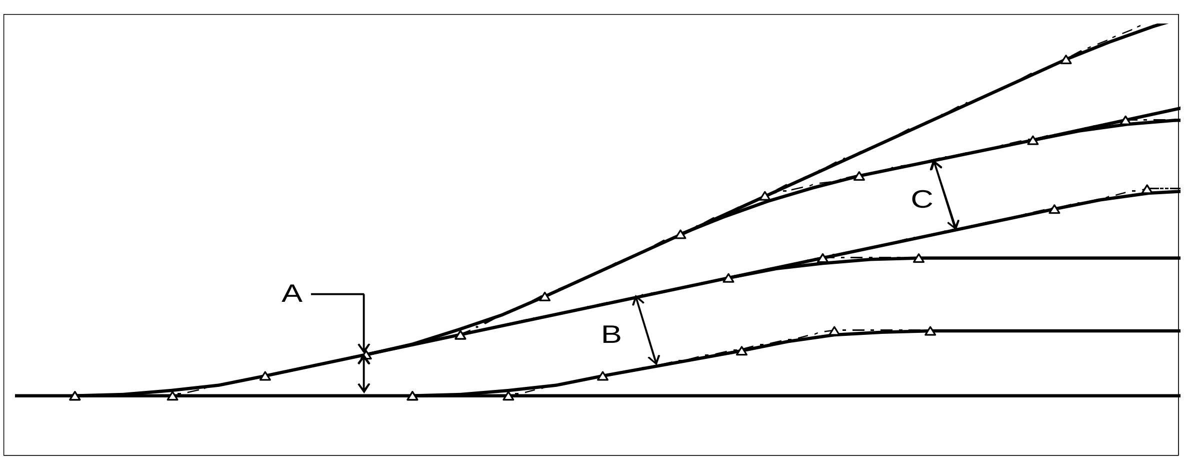


The following considerations shall be used in the development of these designs:

- Separation at switch point – Recommended: 9.00 feet, Minimum: 9.0 feet.
- Space between track centers – Recommended: 20.0 feet, Minimum 18.0 feet.
- Space between track centers with switch points approximately opposite – Recommended: 25.0 feet; Minimum 20.0 feet; if at least one switch machine can be turned away.

The above considerations are required to provide space for the switch tie sets of adjoining turnouts to fit together without overlapping. While overlapping tie sets are constructible, these are undesirable because they create the need for non-standard, site-specific ties and fixtures that add to yard cost and complexity. These space requirements generally will provide adequate clearance for switch machines to be located clear of adjacent tracks. However, the specifics of each yard layout may create localized conditions of interference. Ultimately the yard ladders must be laid out with dimensionally accurate switch machines and tie layouts, and adjacent roads and facilities must be overlaid to verify fit.

Figure 4-9: Double Ladder, Track Space Requirements (6 Diverging Tracks Illustrated)



Chapter 5

Trackwork

HSR 13-06 - EXECUTION VERSION

Revision	Date	Description
0	02 Mar 12	Initial Release, R0
0.1	Dec 2012	EXECUTION VERSION

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Acronyms

AAR	Association of American Railroads
AREMA	American Railway Engineering and Maintenance-of-Way Association
CFR	Code of Federal Regulations
CWR	Continuous Welded Rail
EFB	Electric Flash Butt
EN	European Standard (EuroNorm)
FRA	Federal Railroad Administration
LVT	Low Vibration Track
RBM	Rail Bound Manganese
WBM	Welded Boltless Manganese
ZST	Zero Stress Temperature

5 Trackwork

5.1 Scope

This chapter provides the basis of design for track materials and components for both ballasted and non-ballasted trackforms. This chapter is not intended to be a specification for track materials or track construction.

The objective of this chapter is to define the standards and major components of track for design speeds of 250 mph. The track shall also be compatible with equipment having Association of American Railroads' running gear. Track gauge is standard—that is 56-1/2 inches measured between points 5/8 inch below the top of the head of the rail. The general basis for materials standards shall be the standards of the American Railway Engineering and Maintenance-of-Way Association (AREMA). Some reference to and use will be made of other standards, European and Asian, as appropriate. Exotic or complex components shall not be used any more than necessary for the track to perform its function.

Rails shall be continuously welded throughout, including through turnouts. Expansion joints shall not be used.

5.2 Regulations, Codes, Standards, and Guidelines

Refer to the *General* chapter for requirements pertaining to regulations, codes, and standards. Certain requirements of the Federal Railroad Administration (FRA), among them:

- Code of Federal Regulations (CFR)
  - Title 49, Part 213, Track Safety Standards, generally and also in particular Subpart G – Train Operations at Track Classes 6 and Higher.

Various codes and standards referenced herein include but are not necessarily limited to the following:

- American Railway Engineering and Maintenance-of-Way Association (AREMA) Manual for Railway Engineering, in particular the following chapters:
  - Chapter 1: Roadway and Ballast
  - Chapter 4: Rail
  - Chapter 5: Track
  - Chapter 17: High-Speed Rail Systems
  - Chapter 30: Ties

- American Railway Engineering and Maintenance-of-Way Association (AREMA) Portfolio of Trackwork Plans, commonly referenced as the AREMA Portfolio.
- European Standards (EN for European Norms)
  - EN 13674-2, Railway Applications – Track-Rail-Part 2: Switch and Crossing rails used in conjunction with Vignole railway rails 46 kg/m and above
  - EN 13674-3, Railway Applications – Track-Rail-Part 3: Check rails

5.3 Track Components and Materials

5.3.1 In-Service Conditions

Track and track components shall be designed and fabricated to be durable and perform under the prevailing and extreme climatic and environmental conditions occurring within the geographic extent of the system. For climatic conditions, see the *General* chapter.

5.3.2 Interface between Track and Track Support Systems

For track-structure interaction, refer to the *Structures* chapter.

For grounding and bonding requirements of the track support structure, refer to the *Grounding and Bonding Requirements* chapter.

5.3.3 Clearances around Tracks

Between the Rails – There shall be nothing between the rails higher than 4 inches below the plane of the top of rails with the exception of required power and signal devices and connections, joint bars and bolts, and turnout rails which include frog guard rails.

Outside the Rails – There shall be nothing outside the rails higher than 4 inches below the plane of the top of rails to a minimum of 6.50 feet offset from track centerline with the exception of 6.25 feet offset for long aerial structures and with the exception of required power and signal devices and connections, rail braces, joint bars and bolts, and turnout rails.

Clearances related to passage of vehicles and offsets to fixed elements above the plane of the rails are described in the *Trackway Clearances* chapter.

These requirements do not apply to station platforms or end steps and ramps down from station platforms that have offsets not less than 6 inches greater than the platform edge offset. These requirements do not apply to non-revenue tracks that have speed limits of 25 mph or less.

5.3.4 Maintenance Considerations

Durability, low maintenance, and ease of maintenance shall be a primary consideration in selection of track types and track components. Maintainability shall be second only to

performance requirements in selection of appropriate components. Components that require adjustments shall be avoided. Components that require full or partial disassembly to be inspected shall be avoided.

Under normal circumstances, maintenance work will be performed outside of normal service hours.

5.3.5 Track Drainage

Positive drainage shall be provided for spaces between the tracks. Refer to the *Drainage* chapter for trackway drainage requirements.

5.3.6 Seismic and Ground Movement Considerations

The alignment crosses several faults, both active and inactive. The potential frequency and magnitude of movement for each of these shall require analysis and specific appropriate mitigations developed on a case-by-case basis. Use of non-ballasted track across these zones shall be the base case for the analysis. Refer to the *Seismic* chapter.

5.3.7 Electric Properties

The minimum electrical resistance from rail to rail shall not be less than 10 ohms per thousand feet.

The minimum electrical resistance from rail to rail shall not be less than 20,000 ohms for each set of rail supports.

5.3.8 High-Speed Tracks

Homogeneity in track type is recommended. Frequent changes in trackform shall be avoided. The continuous minimum length of any trackform shall not be less than the minimum length of alignment segment for a run time of 1.8 seconds at the design speed of the segment, as specified in the *Track Geometry* chapter.

5.3.9 Lower Speed Main Tracks and Station Tracks

Non-ballasted track shall be used for all tracks adjacent to and to 75 feet beyond the end of station platforms. Use of non-ballasted track is recommended for all tracks carrying revenue trains, lead tracks into yards, and stub end storage and refuge tracks associated with stations.

5.3.10 Yard, Storage, and Low Speed Tracks

Yard, storage, and low speed tracks may be either ballasted or non-ballasted tracks. Ballasted track is the recommended trackform in yards. There will also be special track types in certain areas of the yards and shops, such as embedded rails in shop floors, pedestal supported tracks over pits, and other non-standard types.

5.4 Rail

5.4.1 Selected Section

The 141RE rail section shall be used for high-speed tracks on the California High-Speed Train Project (CHSTP).

The outline and properties of the 141RE section as given in the AREMA Manual, Chapter 4, Part 1 are presented in Figure 5-1:

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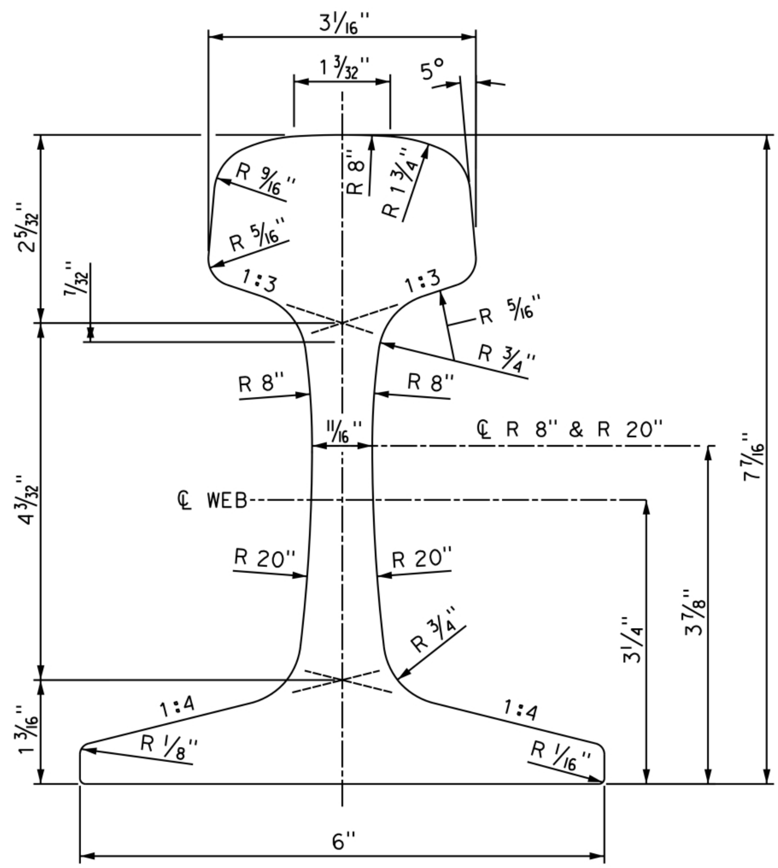
Figure 5-1: AREMA 141 RE Rail



141 RE RAIL SECTION

1. Rail Area, head Rail Area, web Rail Area, base Rail Area, whole rail	5.3724 3.5547 4.8701 13.7972	$inch^2$ $inch^2$ $inch^2$ $inch^2$
2. Rail Weight (based on specific gravity of rail steel = 7.84)	140.7002	lb/yd
3. Moment of Inertia about the neutral axis	100.44	$inch^4$
4. Section modulus, head Section modulus, base	25.24 28.97	$inch^3$ $inch^3$
6. Lateral moment of inertia	14.91	$inch^4$
7. Lateral section modulus, head Lateral section modulus, base	9.74 4.97	$inch^3$ $inch^3$
8. Height of shear center above base	1.88	inches
9. Torsional rigidity is 'KG' Where G is the modulus of rigidity and: K = (error for K >10%)	5.97	$inch^4$

5.4.2 Use of Standard and High Strength Rails

Running rail, rails in turnouts including switch point rails, frog rails, and guard rails shall comply with the metallurgy, hardness, and strength requirements of the AREMA Manual, Chapter 4, Part 2, Standard Strength or High Strength as appropriate.

Either Standard Chemistry or Low Allow Chemistry may be used for standard strength rail. Low Alloy Chemistry shall be used for high strength rail.

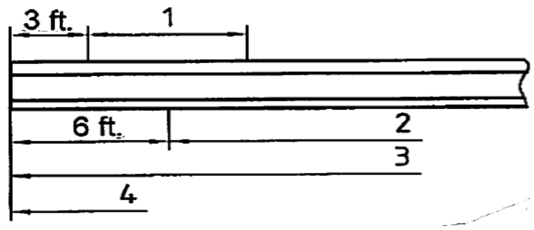
Standard Strength Rail shall be used throughout except in the following areas where High Strength Rail shall be used:

- Revenue service tracks having a radius of 2,000 feet or less
- Yard lead tracks having a radius of 1,500 feet or less

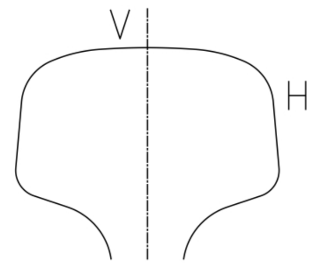
5.4.3 Rolling Tolerances and Straightness of Rails

Straightness surface flatness and twist tolerances given in Table 5-1 shall be substituted for those given in the AREMA Manual, Chapter 4.

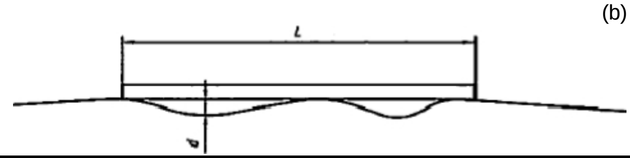
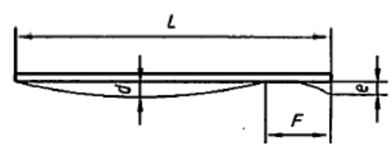
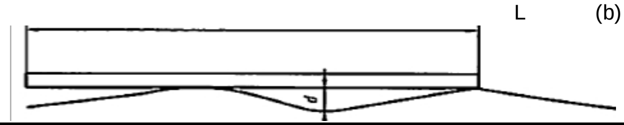
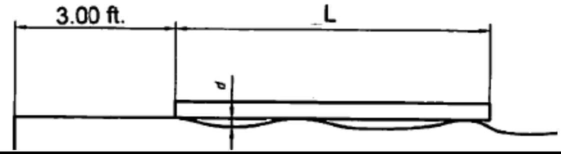
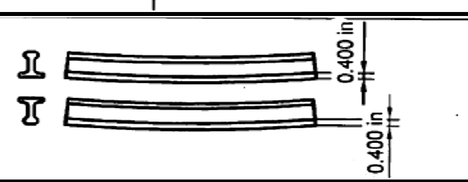
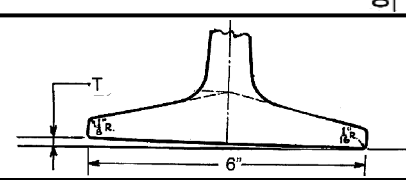
Table 5-1: Rail Straightness Requirements



1. Overlap
2. Body
3. Whole Rail
4. End "E"



1. V and H Location of flatness measurements.
2. The position of H is 5/8" below top of rail.

		Class A d	Class A L	
BODY FLATNESS [(a)]	Vertical V	≤0.012 in. and ≤0.08 in.	10 ft.[(c)] and 3 ft.[(c)]	(b) 
	Horizontal H	≤0.018 in.	5 ft.[(c)]	
ENDS [(a)]	End "E"	6 ft.		(b)  If e > 0 F ≥ 2 feet
	Vertical straightness	d≤0.016 in. and d≤0.012 in. and e≤0.008 in.	6 ft. and 3 ft.[(d)]	
	Horizontal straightness	d≤0.024 in. and d≤0.016 in.	6 ft and 3 ft.[(d)]	L (b) 
OVERLAP [(a)]	Length of overlap	6 ft.		(b)  3.00 ft. L
	Vertical flatness V	d≤0.012 in.	6 ft.[(c)]	
	Horizontal flatness H	d≤0.024 in.	6 ft.[(c)]	
WHOLE RAIL	Upsweep and downsweep	0.40 in.		 0.400 in 0.400 in
	Side sweep	Curve radius R>5000 ft.		
TWIST	Whole Rail	T≤0.100 in.		 T 6"
	Within any 3 ft.	T≤0.020 in.		

Notes:

(a) Automatic measurement equipment shall measure as much of the rail as possible but, at least the body. If the whole rail satisfies the body specification, then measurement of end and overlap is not mandatory.

(b) Automatic measurement techniques are complex and are therefore difficult to define but finished rail flatness shall be capable of being verified by straight edge as shown in the above figure.

(c) 95% of delivered rails shall be within limits specified with 5% of rails allowed outside tolerances by 0.004 inch.

(d) Reference L sliding over end E.

5.5 Rail Welding and Joints

Rails in all tracks shall be welded and welded by the Electric Flash Butt (EFB) welding method to the greatest extent practical. The lengths of strings of welded rail shall be as long as practical. Use of Thermit welds shall be limited to locations and conditions where use of EFB welding is impractical. Use of bolted joint bars shall be limited to insulated joints and other locations as described in Section 5.5.3.

5.5.1 Rail Welding Standards

AREMA Manual Requirements – Welding of rail shall be in accordance with the standards of the AREMA Manual Chapter 4, Rail; Part 3, Joining of Rail and the following sections.

- Straightness – The straightness of welds shall be to standards not less than that for the rail between welds.
- Staggering of Welds – Welds in opposite rails of the same track shall not be set square with each other. They shall be staggered. The amount of stagger shall be in the range of 15 to 33 feet. In constrained locations such as turnouts, the stagger shall be between two and three spacings of the rail support.

5.5.2 Zero Stress Temperature

Rails shall be installed so as to be free of longitudinal stress, that is in neither compression or tension at the temperatures given in Table 5-2.

Table 5-2: Continuous Welded Rail (CWR) Zero Stress Temperature (ZST)

Section Limits	ZST, Open Air (°F)	ZST, Tunnel (°F)
San Francisco to 22 miles south of San Francisco	110	90
22 miles south of San Francisco to east side of Pacheco Pass	115	95
East side of Pacheco Pass to 30 miles south of Bakersfield	120	100
Sacramento to Junction with SF – LA line	125	105
30 miles south of Bakersfield to 25 miles north of Los Angeles	115	95
25 miles north of Los Angeles to Los Angeles to Anaheim	120	100
Los Angeles to 35 miles north of San Diego	120	100
35 miles north of San Diego to San Diego	115	95

5.5.3 Bolted Joints – Insulated and Non-insulated

Rail joints not welded, both insulated and non-insulated, shall be bonded. Bonded joints shall have full contact D-bars of a cross section appropriate for the 141RE rail section. Joints shall be in accordance with the requirements of AREMA Manual Chapter 4, Part 3, Joining of Rail except

as modified herein. Joints shall not to be installed either square or at the same spacing as axle spacings in the trucks. In certain shop tracks in or adjacent to buildings, the use of non-bonded joints may be necessary.

Joints in tracks carry in-service passenger trains or other tracks have a speed limit of 30 mph or more shall be eight-hole bars not less than 50 inches long. The fourth hole each way from center of bar and end of rail shall be spaced 6 inches from the third hole. The end 9 inches of the bar shall be tapered from full width of bar to not extend beyond the rail head at the end of bar. Joints in tracks outside yards and other facilities that do not carry in-service passenger trains and have a speed limit of less than 20 mph or less may have 6-hole bars.

Insulated joints shall be located to meet the requirements of the signal and train control system, refer to the *Automatic Train Control* and *Yard Signaling* chapters. Non-insulated joints may be used in locations where use of electric flash butt welds is impractical and use of thermit welds is inadvisable.

5.5.3.1 Bonded Joints

When installed in revenue track having a design speed of 60 mph or higher, straightness shall be as follows:

- Vertical misalignment – Crown: +0.015 inch, Dip: zero, measured with a 36-inch straightedge
- Horizontal misalignment – 0.020 inch, measured with a 36-inch straightedge
- Vertical offset – 0.015 inch
- Horizontal offset – 0.010 inch

For tracks having design speeds lower than 60 mph, the straightness limits given in the AREMA Manual may be used.

5.5.3.2 Joint Stagger

Joints in opposite rails of the same track shall not be set square with each other.

Insulated joints shall be staggered between 4 feet and 6 feet.

Non-insulated joint stagger shall be to the same limits as that given for welds.

5.5.3.3 Non-Bonded Temporary Joints

Temporary joints shall have 36-inch-long, 6-hole joint bars in accordance with the requirements of the AREMA Manual, Chapter 4, Part 3. Temporary joints shall be staggered to the limits given above.

5.6 Rail Fastenings

The spring clip shall be the Pandrol Fastclip or a clip of similar characteristics. Any alternative clip proposed shall be tested and all characteristics proven to be equal to or better than the following:

- The rail fastening system shall consist of the smallest practical number of pieces.
- Fastening systems shall be boltless to the greatest extent practical. Spring clips shall not be held in position by bolts or any other method that uses a separate piece beyond the spring clip insulator.
- The spring clip load deflection curve shall be within 15 percent of a straight line for deflections of between 0 and 3/8-inch. The zero position is defined as the spring clip position when fully applied to the rail base and with the rail firmly seated.
- Strength requirements per rail seat:
  - Longitudinal – not less than 2,400 pounds without slippage of the rail
  - Lateral movement of the rail base not more than 1/4-inch under a load of 8,000 pounds

5.7 Other Track Material

Other track material consists of other track features that are common to both ballasted and non-ballasted tracks (e.g., guard rails, bumping posts, etc.).

5.7.1 Emergency Guard Rails

Emergency guard rails and similar devices shall not be used.

5.7.2 Bumping Posts – Sliding and Fixed

Fixed bumping post similar to the Hayes type shall be installed at the end of track in yards and shops, and other tracks where the design speed for trains or equipment is 20 mph or less.

Bumping post having either hydraulic or friction devices allowing a movement of not less than 10 feet shall be used at the ends of all tracks that are designed to carry revenue trains. The bumping post shall be capable of stopping a 16-car train at a speed of 5 mph.

Wheel stops may be used on tracks which are designed to hold only maintenance equipment and also have a design speed of 20 mph or less.

5.7.3 Derails

The FRA requires that all tracks connecting to tracks carrying passenger trains operating at speeds above 110 mph shall be equipped with a derail that is interconnected with the signal system (49 CFR 213, paragraph 213.357). The type of derail is not specified in the CFR.

Derails shall be located at or beyond the point where track centers are 16.50 feet. For track centers less than 16.50 feet, the derail shall be located at or beyond the point where the tracks achieve their full defined track centers.

5.7.3.1 Switch Point Derails

Each track, other than another track carrying revenue passenger trains, that connects with a track carrying revenue passenger trains shall be equipped with a switch point derail that is interconnected with the signal and train control system. The switch point derail shall be the same as the switch end of a No. 11 turnout up to the point of 18 inches separation between gauge lines.

Each derail shall be clearly visible. When in a locked position, a derail shall be free of any lost motion which would prevent it from performing its intended function.

The derail interconnection shall be such that the derail operation coincides with the turnout operation.

An additional 4.00 feet of deck width, invert width, or roadbed width, as applicable, shall be provided from a point 20 feet in advance of the point of the derail to 300 feet beyond the point of derail. “Beyond” is defined as being in the direction that the derailed vehicle will be traveling.

5.7.3.2 Block Derails

Block derails shall be similar to the Hayes type. Block derails shall be applied on tracks used to store maintenance equipment and other locations where the speed limit will be 20 mph or less. They may be either powered or non-powered as the situation requires.

An additional 4.00 feet of deck width, invert width, or roadbed width, as applicable, shall be provided from a point 20 feet in advance of the point of the derail to 80 feet beyond the point of derail. “Beyond” is defined as being in the direction that the derailed vehicle will be traveling.

5.8 Track Support Systems

5.8.1 Track At-Grade

The top of the trackbed shall be graded so that there is a 24:1 (H:V) minimum cross-slope towards the adjacent ditch, subdrain system, or embankment slope.

5.8.1.1 Subgrade

Subgrade is the trackbed that supports the railroad loads transmitted through the rails, ties, ballast, and subballast. Subgrade shall be sloped and side ditches or subdrain system shall be provided to keep the subgrade free of standing water.

The designer shall analyze the existing subgrade and determine whether the material is considered to be compressible, soft, loose, or otherwise unsuitable to support the design dead and live loads. If the existing subgrade is compressible, soft, loose, or otherwise unsuitable as described in the Standard Specifications, then it shall be either (1) removed and replaced with approved compacted backfill or (2) stabilized with ground improvement techniques to ensure settlement criteria in the *Geotechnical* chapter.

5.8.1.2 Subballast or Asphalt Underlayment

Where the ground is stable and soils are not subject to pumping through the subballast, subballast may be used under the track ballast. Where the ground is subject to pumping or the subgrade material is subject to volume changes with changes in moisture content, an asphalt base course underlayment shall be used.

Subballast – The subballast material shall be based on the standard aggregate base course used by Caltrans in the geographic area of application. The minimum thickness of subballast shall be 9 inches. A thicker layer may be required. The thickness shall be determined by analysis of the support required.

Asphalt Underlayment – The asphalt underlayment shall be based on the standard asphalt base course used by Caltrans in the geographic area of application. The minimum thickness shall be 6 inches. The width of the asphalt section shall be beyond the influence line brought down to the bottom of the asphalt underlayment at a slope of 1:1 (H:V) but shall not extend beyond the toe of the ballast. The area between the edge of asphalt underlayment and top of slope or ditch line shall have a layer of subballast of the same or greater thickness as the asphalt underlayment.

5.8.2 Track on Concrete Base

5.8.2.1 Track on Aerial Structures and Bridges

5.8.2.2 Track in Tunnels

5.8.2.3 Track in Trenches or Cut-and-Cover Structures

5.8.3 Transitions between Trackforms

5.9 Non-Ballasted Track

The design depth from top of rail to the top of structure, subballast, or equivalent at the track centerline shall not be less than 2.50 feet, refer to Standard and Directive Drawings.

The average fastener spacing in this type of trackform shall be 27 inches. Rail supports need not be directly opposite each other. Spacing may be varied between 24 inches and 30 inches, with the average spacing being within ±1.0 inches of the 27 inches over any 10 fasteners.

The vertical spring rate of the non-ballasted track system shall be designed to be 3000 lb/in/in. This requirement does not apply to tracks in yards.

It may be assumed that each fastener carries about 25 percent of the wheel load for purposes of deflection calculation. Deformation of the elastomer shall not exceed 10 percent of the thickness of the elastomer layer.

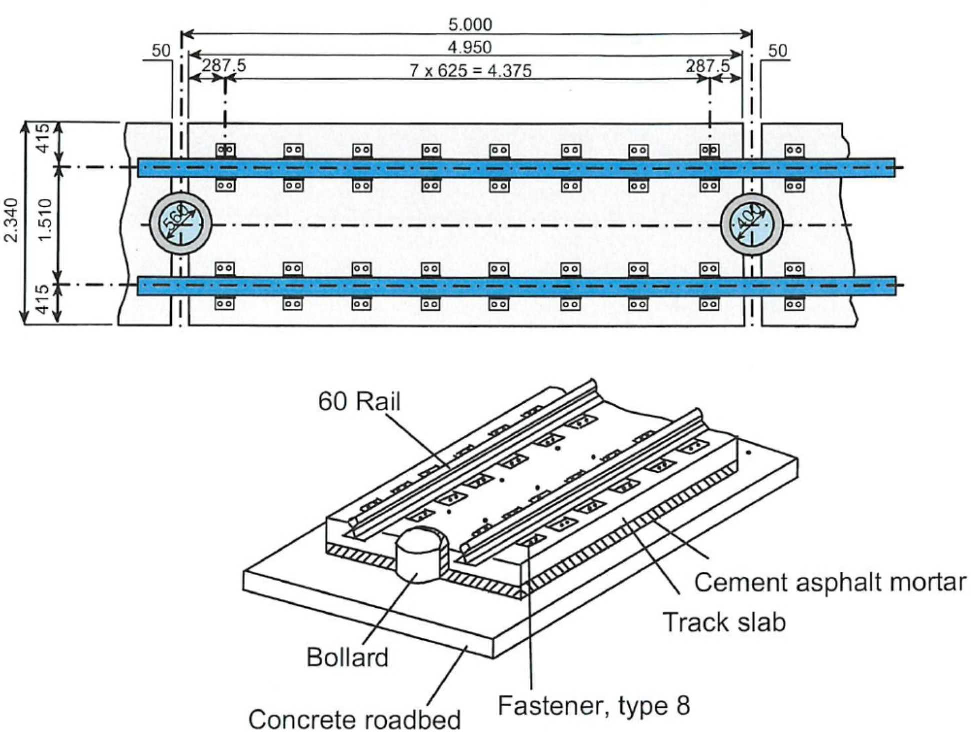
Provision for passage of signal and train control cables across the trackform and from outside to between the rails shall be provided. The location, spacing, and nature of these provisions will be shown on Standard and Directive Drawings.

For additional guidance on vertical alignment and grade limitation, refer to the *Track Geometry* chapter.

5.9.1 Precast Segmental Slab Non-Ballasted Track

The recommended trackform shall be the non-ballasted precast segmented slab type trackform. The precast slab system will be similar to the standard non-ballasted trackform used in the Shinkansen system. Figure 5-2 provides a typical layout of this trackform. A standard design for the CHSTP will be developed.

Figure 5-2: Precast Segmental Non-Ballasted SlabTrack



Modifications and modernizations made to this system for application to the CHSTP should include the following:

- Use single piece transit system type rail fasteners instead of the multi-piece rail fasteners. See Section 5.9.2.
- Rationalization of dimensions
- Modification of bollard size and shape
- Development of a precast segmented slab track design specific to the California conditions and including "lessons learned" since the original design will follow at a later date.

5.9.2 Transit System Type Plinth and Fasteners

The transit system type plinth and fasteners may be used. This type is very familiar to contractors that have built tracks for transit systems in the U.S. It can be designed to be applicable for high-speed tracks.

The ratio between the quasistatic deflections and the dynamic deflections under forces applied and released at a rate approximating that of a train passing at full speed shall not be greater than 2:1 (H:V).

The fastener shall not be dependent upon the elastomer in shear to prevent excessive lateral or longitudinal movement of the rail in relation to the track slab.

5.9.3 Embedded Tie Blocks in Elastic Boots

In areas where there is little or no potential for seismic activity, ground movement or structure movement, and maximum speed is 125 mph or less, a system consists of embedded tie blocks in elastic boots, commonly called Low Vibration Track (LVT) may be used.

For booted block systems, all the requirements for concrete tie fasteners shall apply, except the pullout force may be reduced to 6,000 pounds so long as all other requirements are met.

Figure 5-3: Low Vibration Track Embedded Tie Block

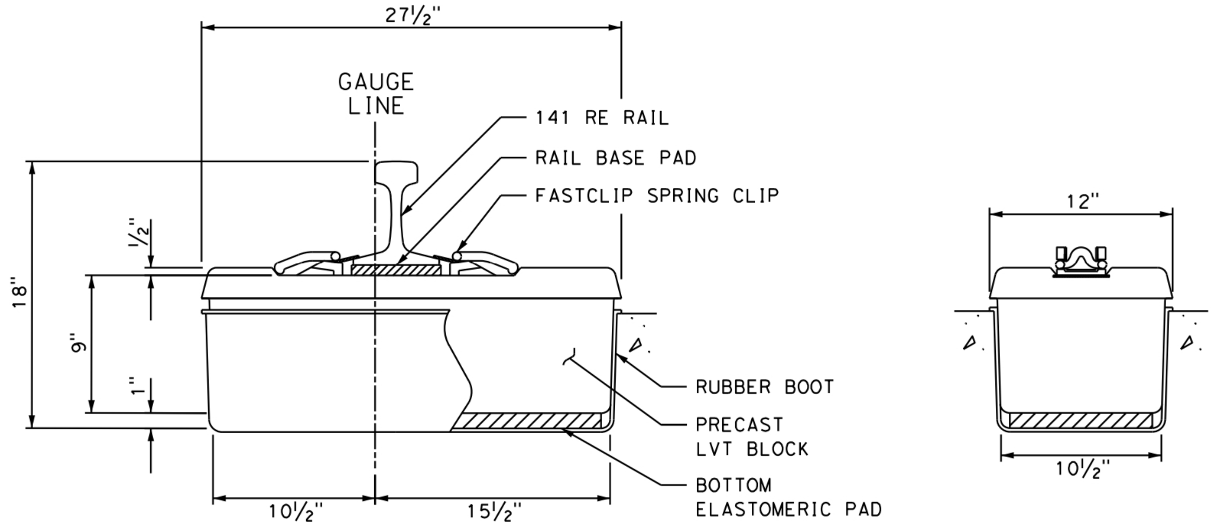


Figure 5-4: Example of Low Vibration Track, Level

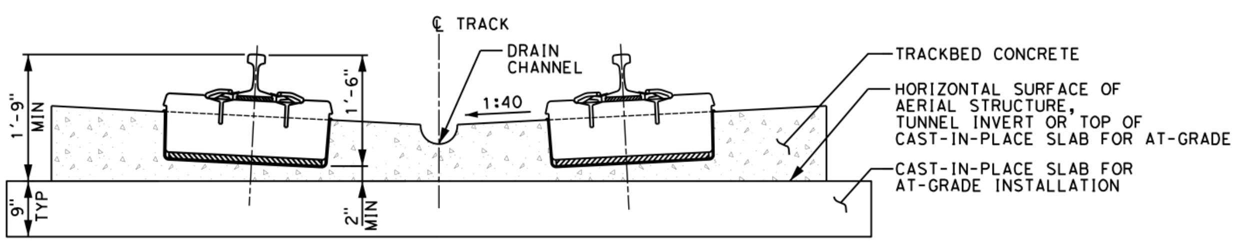
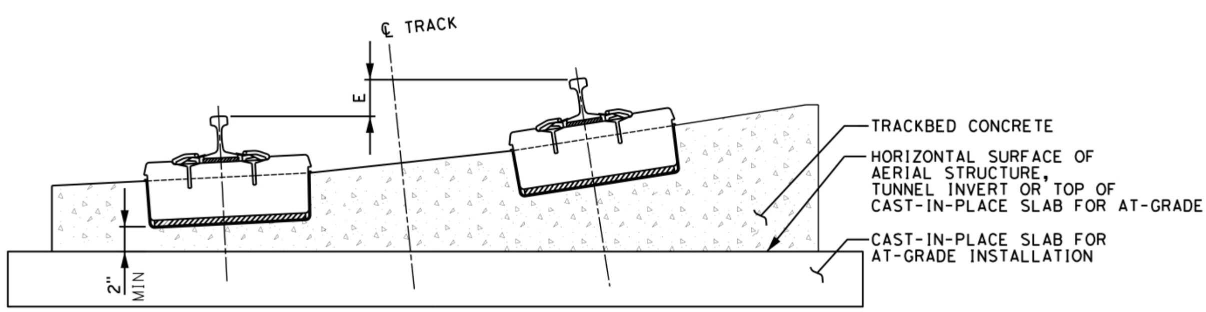


Figure 5-5: Example of Low Vibration Track with Superelevation



5.9.4 Special Considerations in Seismically Active and other Unstable Areas

In areas subject to ground movement from seismic activity, the Precast Segmental Non-Ballasted Slab track shall be the basis for the non-ballasted trackform. For these areas, the bollards shall be taller than normally required and the slab supporting the slabs shall be wider.

The minimum length of this type of trackform and the exact amounts of the additional widening and heights shall be based on the potential amount of movement.

5.10 Ballasted Track

The design depth from top of rail to the top of structure, subballast, or equivalent at the track centerline shall not be less than 2.50 feet, refer to Standard and Directive Drawings. For short length structures, the design depth from top of rail to the structure deck or invert shall not be less than 2.75 feet, plus allowance for waterproofing layer where it is used.

For additional guidance on vertical alignment and grade limitation, refer to the *Track Geometry* chapter.

5.10.1 Concrete Ties

Ballasted tracks shall be constructed with concrete crossties to the greatest extent practical.

5.10.1.1 Dimension and Properties

Concrete crossties shall be designed and fabricated in accordance with the requirements of the AREMA Manual Chapter 30, Ties, Part 4, Concrete Ties, including strength and other requirements with the following modifications:

- Ties – shall be scallop sided and equipped for the Pandrol Fastclip fastening system.
- Rail seats – shall provide a 1:40 (H:V) slope rail inclination.
- Weight – shall not be less than 600 pounds and not more than 750 pounds each.
- The minimum tie dimensions shall be the following:
  - Length – Crossties – Not less than 8.25 feet long and not more than 8.5 feet.
  - Width at bottom – Not less than 10.25 inches and not more than 11 inches
  - Width at top – Not less 7.25 inches and not more than 9 inches, but no greater than the bottom width minus 2.5 inches.
  - Thickness of crossties at ends – Not less than 8 inches and not more than 9 inches.
  - Thickness of crossties at center – Not less than 6.25 inches and no thicker than 0.50 inch less than the thickness at the ends.

5.10.1.2 Rail Fastening System

In addition to the requirements listed in Section 5.6, the following requirements shall apply:

- Bolted baseplates shall not be used on concrete ties in plain line.

- Where bolted baseplates are required, for example in turnouts, female inserts in the ties shall be used. There shall be no exposed threads or threads positioned so that a separate cap is required to cover the threads.
- Inserts in concrete ties shall be able to withstand a pull out force of 12,000 pounds. This applies to both spring clip inserts and insert to hold baseplates that support the rails.
- Inserts in concrete ties shall be able to withstand a torque of 250 foot-pounds. This applies to both spring clip inserts and insert to hold baseplates that support the rails.
- Rail seat pads shall be used between the rail base and the concrete tie.
    - Rail seat pad stiffness shall be between 1,500,000 pounds per inch and 3,000,000 pounds per inch for a pad that is 6 inches by 8 inches in area.
    - Where bolted baseplates are used, a pad of the same properties and material shall be used, but it may be either between the baseplate and the tie or the baseplate and the rail.

5.10.1.3 Placement and Spacing

Concrete ties shall be spaced at an average of 27 inches in main tracks, station tracks, and other high volume tracks. The spacing shall be 30 inches in yard tracks having radii of 1,100 feet or greater. For lesser radii, the spacing shall be 24 inches within the curve and associated spirals or to 50 feet beyond the ends of the curve on curves without spirals.

5.10.2 Wood Ties and Other Types of Ties

Wood ties are acceptable in yard tracks and other tracks that have a speed limit of 40 mph or less. Alternate types of ties, such as plastic, reconstituted wood, etc. shall not be used. No special fastening devices are required.

Dimensions – The standard wood tie shall be manufactured and treated in accordance with the requirements of the AREMA Manual, Chapter 30, Part 3, Solid Sawn Timber Ties. The nominal dimensions of the ties shall be 7 inches by 9 inches by 8 feet 6 inches.

Placement and Spacing – Wood ties shall be spaced at an average of 21 inches in main tracks, station tracks, and other high volume tracks. The spacing shall be 24 inches in yard tracks having radii of 1,100 feet or greater. For lesser radii, the spacing shall be 21 inches within the curve and to 50 feet beyond the ends of the curve.

5.10.3 Ballast

- Materials
    - AREMA Manual Chapter 1, Part 2, Ballast.

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- Gradation
  - Revenue tracks, yard leads, and other tracks where employees are unlikely to be walking: Size No. 24 as given in the AREMA Manual Chapter 1, Part 2 Table 1-2-2. Recommended Ballast Gradations
  - Yard tracks and other tracks where employees are likely to be walking: Size No. 4 as given in the AREMA Manual Chapter 1, Part 2 Table 1-2-2. Recommended Ballast Gradations
- Minimum Depth of Ballast under Rail Seats
  - On earthworks – 12 inches
  - On short length structures – 15 inches, not including thickness of waterproofing, etc.

5.11 Turnouts and Other Special Trackwork Components

The requirements of this section relate to materials and component types to be used in turnouts and other special trackwork. Only major components are discussed. Details of location and application of these components and details of minor components are shown on the Standard and Directive Drawings. Placement of and internal geometry of turnouts and associated connecting tracks is described with the alignment related requirements.

5.11.1 Rails in Special Trackwork

The shape and properties of the rail used in special trackwork shall be the same as that used in open track. Rails through turnouts in revenue tracks shall be set at an inclination of 1:40. Standard Strength Rail shall be used except High Strength Rail shall be used where the following conditions apply:

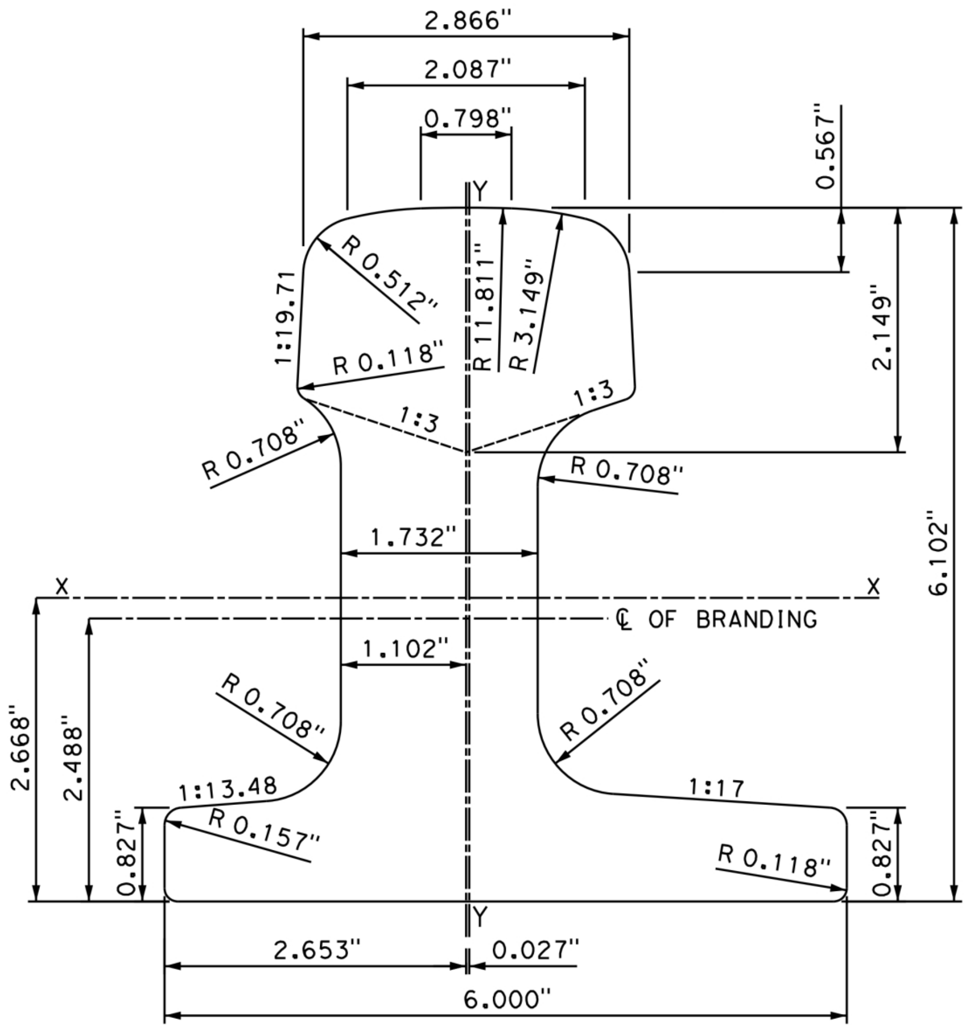
- Turnouts in revenue service tracks having an internal radius of 3,000 feet or less and where not less than 30 percent of the traffic operates on the curved side of the turnout.
- Turnouts in yard lead tracks having a radius of 2,000 feet or less and where not less than 30 percent of the traffic operates on the curved side of the turnout.

5.11.2 Switch Rails

Switch rails shall be of the EN 60E1A3 section as shown in Figure 5-6 (EN 13674-2 Figure A.7).

Switch point rails shall comply with the metallurgy, hardness, and strength requirements of the AREMA Manual, Chapter 4, Part 2, for High Strength Rails.

Figure 5-6: EN 60E1A3 Asymmetric Switch Rail (EN 13674-2 Figure A.7)

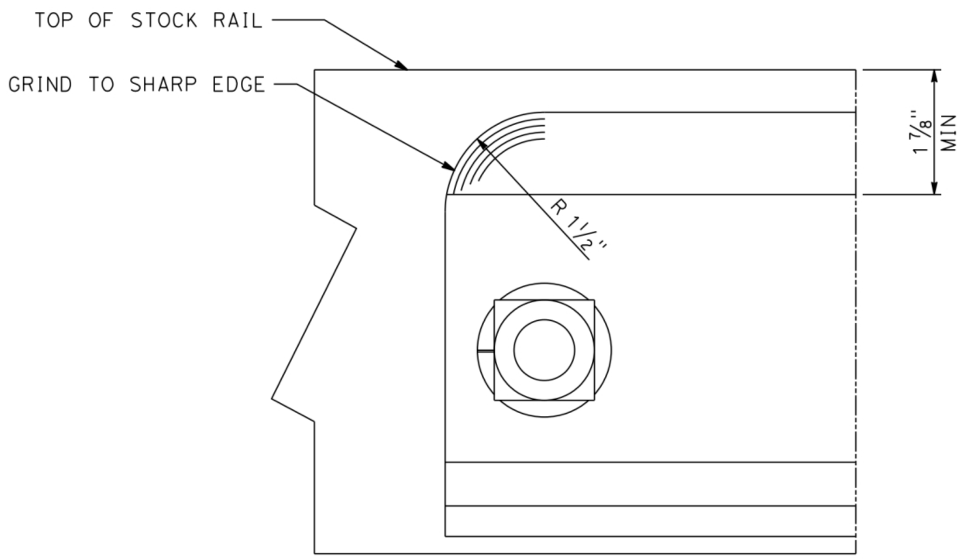


60 E1A3 RAIL SECTION

(NOTE: UNITS CONVERTED FROM METRIC UNITS)

Property	U.S. units	
Centerline of branding	3.002	inches ATR
Mass per meter	168.6	lb/yd
Cross-sectional area	16.51	in^2
Moment of inertia X-X axis	65.42	in^4
Section modulus – Head	19.02	in^3
Section modulus – Base	24.56	in^3
Moment of inertia Y-Y axis	21.56	in^4
Section modulus Y-Y axis, left	8.04	in^3
Section modulus Y-Y axis, right	6.49	in^3

Figure 5-7: AREMA Switch Tip Rounding – Side View of End of Switch Point



Note: from AREMA Portfolio Plan 221

5.11.3 Turnout Frogs

Three types of frogs shall be used, with the type determined by the application.

Wheel contact areas on frogs of all types shall be machined to match the head shape of the 141RE rail section. Rails used in frogs shall comply with the metallurgy, hardness, and strength requirements of the AREMA Manual, Chapter 4, Part 2, for High Strength rails. Manganese steel castings used in frogs shall be explosion hardened. References herein to AREMA Portfolio Plans and other plans are general in nature.

Frogs in high-speed turnouts shall be Movable Point Frogs.

Frogs in low and medium speed turnouts shall be either Rail Bound Manganese (RBM) Frogs, Welded Boltless Manganese (WBM) Frogs, or Spring Frogs.

- RBM or WBM Frogs shall be used for yard turnouts. This type shall be used in revenue tracks where all of the following conditions apply:
  - The design speed for trains on the straight (through) side of the turnout is 90 mph or less.
  - Anticipated train volume on the diverging side is 30 percent or more of the train volume on the through route.
  - Terminal station throat turnouts
  - Turnouts in yard and secondary tracks
- Spring Frogs shall be used where all the following conditions apply:

  - The design speed for through trains on the straight side of the turnout is 110 mph or less.
  - Anticipate train volume on the diverging route is less than 30 percent of the volume on the through route.
  - The turnout is number 20 or less
- Movable Point Frogs, also called Swing Nose Frogs or Crossings, shall be used in turnouts where the design speed of either track is more than 110 mph. This type of frog shall be used for turnouts in lower speed tracks where the conditions permitting one of the other types of turnouts do not exist.

5.11.3.1 AREMA Rail Bound Manganese (RBM) Fixed Frogs

Materials and fabrication of RBM Frogs shall be as shown in the AREMA Portfolio of Trackwork Plans, Plans 623 through 625, except that tapering and planing of the wing rails shall be a two stage planning similar to that shown on AREMA Portfolio Plan No. 504-71 (Note: This is not the current version of this plan). Details of end planing will be shown on Standard and Directive Drawings.

5.11.3.2 Welded Boltless Manganese (WBM) Frogs

A recent development is a one-piece cast manganese steel frog that can be welded into the track. It is an “Americanized” version of the European cast manganese steel frog with welded on rail steel legs which enables it to be welded. This frog design is patented, U.S. patent number 5,170,932. The patent is held by Voest-Alpine Eisenbahnsysteme. The design is also patented in Austria and Germany. Figure 5.8 is provided for illustration purposes. This particular frog is in a freight service main track.

Figure 5-8: Welded Boltless Manganese Frog

Tapering of the wing rails shall be a two stage taper similar to that shown on AREMA Portfolio Plan No. 504-71 (Note: This is not the current version of this plan). Details of end planing will be shown on Standard and Directive Drawings.

5.11.3.3 AREMA Spring Frogs

Materials and fabrication shall be as shown in AREMA Portfolio Plans, 401, 407 and 490, except that tapering and planing of the wing rails shall be a two stage planning similar to that shown on AREMA Portfolio Plan No. 504-71. Note: This is not the current version of this plan. Details of end planing will be shown on Standard and Directive Drawings.

5.11.3.4 Swing Nose (Movable Point) Frogs

There are several variations in design in these frogs. Three examples are shown in the following figures. There are other design variations.

Figure 5-9: Movable Point Frog (1,200 meter radius turnout in JIS 60 kg/m rail)

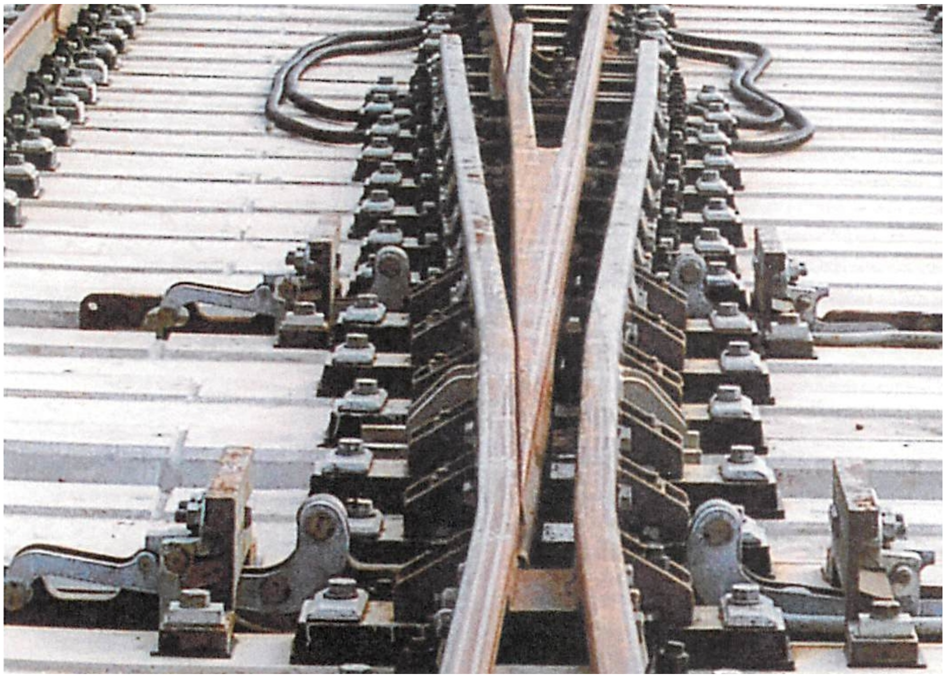
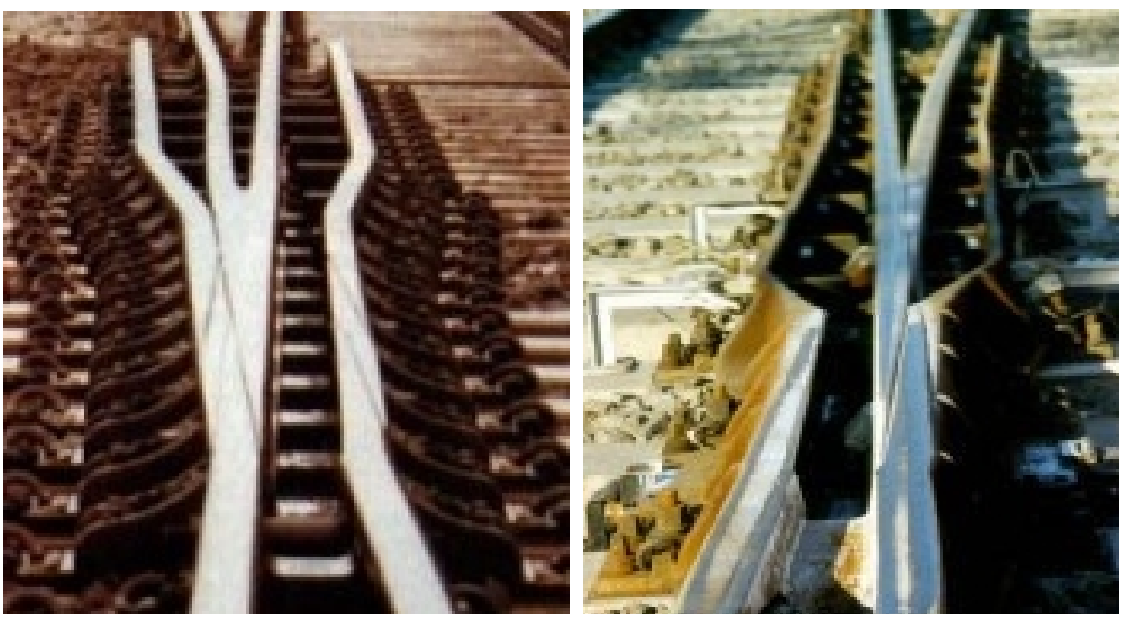


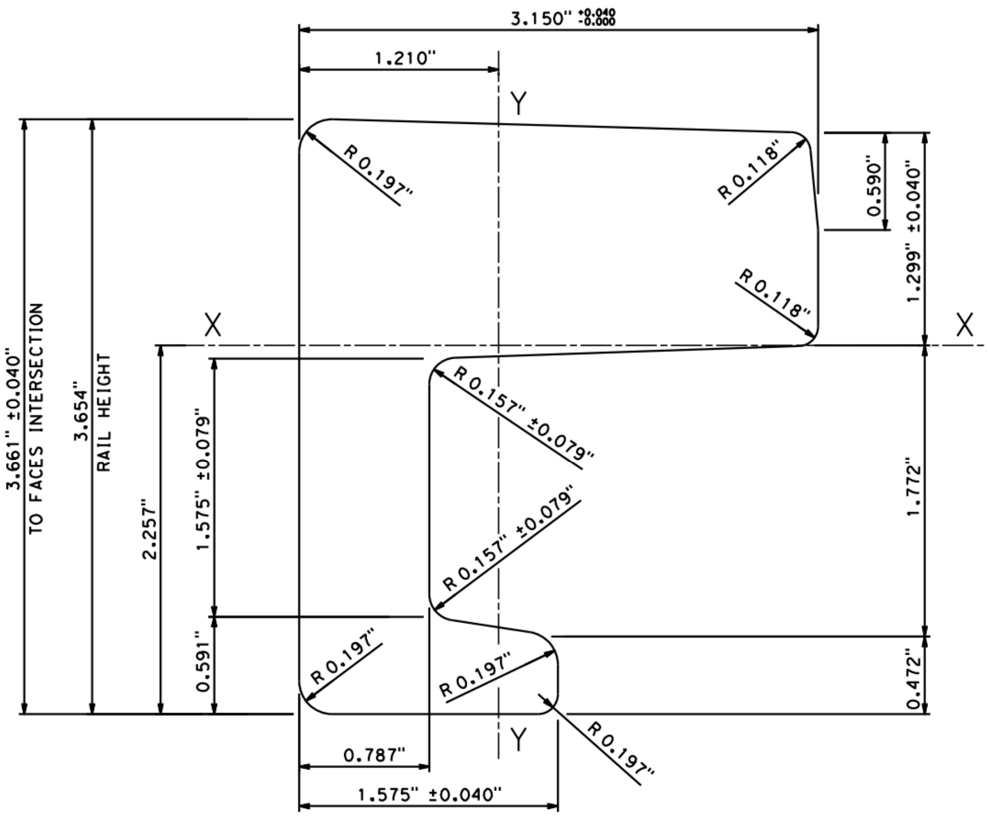
Figure 5-10: Movable Point Frog: Rail Housing (Left) and Manganese Steel Cast Housing (Right)



5.11.4 Turnout Guard Rails (also called Check Rails)

Turnout guard rails shall be of the 33C1 Section as shown in Figure A.1 in EN 13674-3. This section has also been referred to as the U69, UIC33, and RL 1-60. Metallurgy, hardness and strength of the section shall comply with that for High Strength Rail in the AREMA Manual, Chapter 4, Part 2.

Figure 5-11: EN 33C1 Check Rail (EN 13674-3 Figure A.1)



EN 33C1 CHECK RAIL SECTION
(NOTE: UNITS CONVERTED FROM METRIC UNITS)

Property	U.S. units
Mass per meter	66.50 lb/yd
Cross-sectional area	6.51 in^2
Moment of inertia X-X axis	7.14 in^4
Section modulus – Head	5.11 in^3
Section modulus – Base	3.16 in^3
Moment of inertia Y-Y axis	5.26 in^4
Section modulus Y-Y axis, left	4.34 in^3
Section modulus Y-Y axis, right	2.71 in^3

End tapering and planing shall be a two stage planning similar to that shown on AREMA Plan No. 504-71. Note: This is not the current version of this plan. Details of end planing will be shown on Standard and Directive Drawings.

5.11.5 Turnout and Special Trackwork Support Systems

The turnout support system shall be identical with or similar to the support system of the adjacent track. The components used in the support system shall be identical with or similar in nature to those used in the same trackform in track outside the limits of turnouts and special trackwork. That is, where the trackform is ballasted track, the turnouts shall be installed on ballast and ties. Where the trackform is non-ballasted, the turnouts shall be placed on a modification of the same non-ballasted trackform.

5.11.5.1 Non-Ballasted Track

The trackform through turnouts and special trackwork shall be the same as the trackform in the adjacent track. Fastening and support layouts will be shown on Standard and Directive Drawings. For non-standard units, these standard layouts shall be used as guidance along with the following:

- Support spacing through the turnout shall average no more than 24 inches under the switch and 28 inches through the rest of the turnout
- The use of special supports shall be limited to locations where standard supports cannot be made to fit. Rail supports need not be directly opposite each other. Fastener spacing may be adjusted at certain locations if needed to reduce the number of fasteners supporting two rails.

5.11.5.2 Ballasted Track

Turnouts in revenue tracks shall be placed on concrete switch ties. Turnouts within yards shall be placed on wood switch ties. Number 15 and smaller turnouts in other non-revenue tracks outside yards may be placed on either wood or concrete ties. Turnouts larger than number 20 shall be placed on concrete ties.

- Concrete switch ties shall be designed and fabricated in accordance with the requirements of the AREMA Manual Chapter 30, Ties, Part 4, Concrete Ties, including strength and other requirements, the general requirements for concrete ties in this document and the following:
  - Length – Not less than the distance between gauge lines of the outside rails plus 3.50 feet and not more than the distance between gauge lines of the outside rails plus 4.00 feet. Switch ties supporting switch machines, helper rods, or associated operating hardware may be longer as required.
  - Thickness – Portions supporting rails and within 2.50 feet of the gauge line of the rail shall be no less than 8 inches thick and no more than 9 inches thick. Switch ties may be of a constant thickness throughout their length. Extended portions supporting switch

machines, helper rods, or associated operating hardware may be thinner, but no less than 6.50 inches thick.

  - Spacing – Average spacing shall not exceed 27 inches. Range of spacing may be between 24 inches and 30 inches. Spacing with the areas of drive rods and other rodding and signal equipment shall be spaced as needed for these facilities.

- Wood switch ties shall be manufactured and treated in accordance with the requirements of the AREMA Manual, Chapter 30, Part 3, Solid Sawn Timber Ties. The nominal cross sectional dimensions of switch ties shall be 7 inches by 9 inches.
  - Length – Increments in length shall be 1 foot located and positioned so that the difference between switch tie length and distance between gauge lines of the outside rails is between 3.50 feet and 4.50 feet. Switch ties supporting switch machines, helper rods, or associated operating hardware may be longer as required.
  - Spacing – Average spacing shall not exceed 21 inches under the switch and frog areas and shall not exceed 24 inches under the remainder of the turnout. Range of spacing to be between 19 inches and 22 inches under the switch and frog and 22 to 26 inches under the remainder of the turnout.

5.12 Grade Crossings

5.12.1 Yard Traffic Grade Crossings

5.12.2 Main Line Pedestrian Crossings

Chapter 6

Rolling Stock and Vehicle Intrusion Protection

HSR 13-06 - EXECUTION VERSION

Revision	Date	Description
0	02 Mar 12	Initial Release, R0
0.1	Dec 2012	EXECUTION VERSION

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Acronyms

Authority	California High-Speed Rail Authority
Caltrans	California Department of Transportation
CHSTP	California High-Speed Train Project
HST	High-Speed Train
OCS	Overhead Contact System
TCL	Track Centerline

6 Rolling Stock and Vehicle Intrusion Protection

6.1 Scope

This chapter provides the separation requirements for the California High-Speed Train (HST) lines adjacent, overcrossing, and undercrossing transportation systems to protect the HST operating infrastructure from intrusion by rolling stock and vehicles from adjacent transportation systems (i.e., passenger and freight rail tracks and state and local highways/roadways). Application of these requirements will be determined by a site-specific hazard analysis, in conformance with the hazard management process in the CHSTP Safety and Security Management Plan. This chapter is intended to serve primarily as the basis of the track, earthwork, and structural design and mitigation measures where minimum clearances cannot be met. This chapter does not define requirements for access control devices. Refer to the *Civil* chapter for protection of the Authority's right-of-way and facilities against trespass by unauthorized persons and animal intrusion.

6.2 Regulations, Codes, Standards, and Guidelines

Refer to the *General* chapter for requirements pertaining to regulations, codes, and standards. Applicable codes and regulations include but are not limited to the following list.

- Code of Federal Regulations (CFR)
  - Title 49, Part 213, Section 316 for protection of the right-of-way for Class 8 and 9 tracks
  - Title 49, Part 214, Railroad Workplace Safety
- California Public Utilities Commission (CPUC) General Order (GO) No. 26-D
- Federal Railroad Administration (FRA) guidelines regarding the separation and protection of adjacent transportation systems and conventional railroads
  - High-Speed Passenger Rail Safety Strategy published by FRA (November 2009)
- American Railway Engineering and Maintenance-of-Way Association (AREMA) Manual for Railway Engineering
- California Department of Transportation (Caltrans), Manuals and Standards

6.3 Protection of HST Operating Infrastructure from Vehicle Intrusion

The HST operating infrastructure includes the operating envelope, traction power facilities, wayside power cubicles, communication cabinets, cable troughs, piers and walls supporting HST structures shall be protected from intrusion in order to preserve safe and reliable operations. The limits of the HST operating infrastructure is defined as the area from the outer

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face of the Overhead Contact System (OCS) pole foundations in width and from top of the OCS poles to the trackbed supporting the HST tracks in height. In locations where the HST operating infrastructure is located within an open trench, on retained fill, or on an aerial structure, the limit of operating infrastructure shall be extended to the outer face of retaining walls, trench walls, abutments and piers of aerial structures.

6.3.1 Protection Against Intrusion of Conventional Trains

Passenger and freight trains that operate in shared corridors or adjacent to the HST system shall be prevented from entering into the HST operating infrastructure by lateral separation or by a physical barrier (e.g., earth berms, swales, or reinforced concrete walls) when lateral separation between railway systems is insufficient.

6.3.1.1 Protection Measure without Physical Barriers

The preferred protection is to locate HST operating infrastructure at a sufficient distance from conventional railroad systems to avoid intrusion. A lateral distance of 102 feet or greater measured between the closest track centerlines (TCL) of the conventional railroad and HST system does not require a physical barrier for intrusion protection. Alternatively, when the HST track is 10 feet or higher than the conventional railroad top of rail (e.g., HST track on embankment or retained fill), use of a physical barrier for intrusion protection of HST operating infrastructure is not required.

6.3.1.2 Protection Measures with Physical Barriers

When lateral separation between the conventional railroad and HST system is less than 102 feet, physical barriers shall be installed based on site specific hazard analysis. The intrusion protection shall be designed to mitigate the risk that train derailment from adjacent conventional railroad will not intrude into the HST operating infrastructure. For train collision loads, refer to the *Structures* chapter. The intrusion protection is achieved by the following measures:

- Use of a minimum 10-foot-high berm or ditch as an intrusion protection measure when lateral separation between the closest conventional railroad TCL and HST TCL is between 85 to 102 feet for berms; 76 to 102 feet for trenches or for berms if one-half of the berm can be placed on the conventional railroad’s right-of-way and is subject to railroad approval; and 85 to 102 feet for a 5-foot deep trench next to a 5-foot high berm.
- Use of a minimum 10-foot-high reinforced concrete barrier as an intrusion protection measure when lateral separation between the closest conventional railroad TCL and HST TCL does not allow construction of a 10-foot high berm/ditch. This typically occurs when the separation between HST TCL and conventional railroad TCL does not allow construction of berm/ditch as an intrusion barrier.
- Where the side clearance from the closest conventional rail TCL is less than 25 feet to the face of a HST structure, such as a pier or a wall (with the exception of a trench wall), a 6-foot high reinforced concrete barrier shall be constructed at a minimum distance of 1 foot from

the face of the HST supporting structure. Where the side clearance is 12 feet or less, the height of the reinforced concrete barrier shall be 12 feet.

The reinforced concrete barriers shall be designed to protect HST supporting structures from a direct impact by a derailed conventional railroad locomotive.

These guidelines are for physical separation and do not include right-of-way considerations that may require additional separation. Additionally, separation requirements of other owners and operators shall be considered in establishing required separation.

6.3.2 Protection Against Intrusion of Highway Vehicles

Protection against highway vehicles from intruding into the HST operating infrastructure shall be provided through sufficient lateral separation between state highway systems and the HST system, or the installation of barriers. For highway vehicle collision loads, refer to the *Structures* chapter.

6.3.2.1 Protection Against Intrusion of Roadway Vehicles into the HST Operating Infrastructure

Protection against adjacent roadway vehicles from intruding into HST operating infrastructure shall be provided when HST fixed objects are located within the highway Clear Recovery Zone. The September 28, 2011 update to the Caltrans Highway Design Manual established a minimum horizontal clearance requirement for HST fixed objects. As stated, when a high-speed rail corridor is constructed longitudinal to a freeway, expressway, or a conventional highway with posted speeds over 40 mph, the nearest fixed object or feature associated with the operation of the rail facility shall be located at a minimum of 52 feet horizontally from the planned ultimate edge of the traveled way. When the HST alignment is not longitudinal to a Caltrans freeway, expressway, or highway, the standard Caltrans 30 feet requirement shall apply.

If these clearances cannot be provided, a design exception shall be obtained from Caltrans along with appropriate roadside protection mitigation measures, such as installation of a metal beam guard rail or concrete barrier. The appropriate required type of roadside protection shall be site specific and shall consider factors such as traffic volumes, speed, highway geometry, side slopes, accident history, and others. For instance, in locations where high volumes of cargo and tanker trucks are present with high probability of intrusion into HST operating infrastructure, a more stringent intrusion protection is required and shall be provided, such as the modified Caltrans-type concrete barrier up to 7.5-foot-high.

6.3.2.2 Protection Against Intrusion of Roadway Vehicles over the HST Operating Infrastructure

Protection against intrusion of roadway vehicles on grade separated structures onto the HST operating infrastructure below the structure shall be provided. The overhead structure shall be designed to include vehicular railing with sufficient strength to withstand collision loads defined in the *Structures* chapter. The vehicular railing shall extend to the nearest intersection or

100 feet beyond the end of the overhead structure with appropriate taper to redirect vehicles that may travel down the roadway embankment and into the Authority's right-of-way. In conjunction with keeping the roadway vehicle from intruding into the HST operating infrastructure, a protective barrier shall be provided to prevent contact with the OCS, to prevent pedestrians from falling onto, and to reduce the risk of objects being dropped onto the HST operating infrastructure. Refer to the *Overhead Contact System and Traction Power Return System* chapter for minimum requirements of this protective barrier.

Supplemental protection shall be achieved through the use of intrusion detection technology in the fencing around HST operations. When the intrusion detection system is activated, HST operation is stopped, speed is reduced, or other appropriate actions will be taken by the signaling system and/or operations. Intrusion protection, if required, shall be designed in conjunction with the hazard analysis to determine the necessity of the physical barrier.

6.3.2.3 HST Pier and Wall Protection

Where HST piers, trench walls, and other structures are located within the Caltrans Clear Recovery Zone, install Caltrans-type concrete barriers to redirect errant vehicles from intrusion into the HST operating infrastructure and design these structures to the collision loads defined in the *Structures* chapter.

6.4 Containment of HST Rolling Stock

HST rolling stock shall be contained within the operational corridor in order to reduce the potential for intrusion into an adjacent transportation corridor. Strategies to ensure containment include but are not limited to the following:

- Use modern HST rolling stock, which have documented performance likely to minimize the risk of the train derailment and extending beyond it operating envelope. These protections may include use of undercar L-shaped car guards and use of plate springs to prevent rails from large lateral movement.
- Physical elements, such as derailment protection curb or parapet, shall be considered for specific areas with a high risk or high impact of derailment including, aerial structures, tunnels, and approaches to conventional rail and roadway crossings. Refer to Standard and Directive Drawings for minimum side clearance requirements for grade separated structures.
- Ensure the appropriate level of maintenance of infrastructure (per FRA standards) and rolling stocks (per manufacturer requirements), to mitgate the risk of derailment.
- On aerial structures, protection shall be provided by a derailment protection wall designed so that the HST remains within its operating infrastructure. Refer to the *Structures* chapter.

Chapter 7

Civil

HSR 13-06 - EXECUTION VERSION

Revision	Date	Description
0	02 Mar 12	Initial Release, R0
0.1	Dec 2012	EXECUTION VERSION

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Acronyms

AASHTO	American Association for State Highway Officials
AD	Access Deterring
ADA	Americans with Disabilities Act
ADAAG	Americans with Disabilities Act Accessibility Guidelines
AR	Access Restricting
BMP	Best Management Practice
Caltrans	California Department of Transportation
CCR	California Code of Regulations
CHST	*Not Used; use HST for California High-Speed Train*
CHSTP	California High-Speed Train Project
HST	High-Speed Train
MOI	Maintenance of Infrastructure
MUTCD	Manual on Uniform Traffic Control Devices
OCS	Overhead Contact System
RSM	Rolling Stock Maintenance
SA	Station Area
SWPPP	Storm Water Pollution Prevention Plan

7 Civil

7.1 Scope

This chapter provides design criteria to be used in the civil/site design and related work including grading, slope protection, erosion control, site work for Authority's and Non-Authority's facilities, access control, and maintenance and protection of traffic during construction.

7.2 Regulations, Codes, Standards, and Guidelines

Refer to the *General* chapter for requirements pertaining to regulations, codes, and standards. The following codes, guidelines, and references were used in the development of this chapter.

- Americans with Disability Act Accessibility Guidelines (ADAAG) for Buildings and Facilities
- California Code of Regulations (CCR)
- California Public Utilities Commission (CPUC), Applicable General Orders
- American Association for State Highway Officials (AASHTO)
  - A Policy on Geometric Design of Highways and Streets Roadside Design Guide
- American Railway Engineering and Maintenance-of-Way Association (AREMA) Manual for Railway Engineering
- California Department of Transportation (Caltrans)
  - Standard Specifications
  - Standard Plans
  - Highway Design Manual
  - California Manual on Uniform Traffic Control Devices (MUTCD)
  - Stormwater Quality Handbooks

7.3 Grading, Side Slopes, and Retaining Walls for Roadway and Site Embankments

For embankments, cuts, retaining walls, etc. required to support the California High-Speed Train (HST) trackway, refer to the *Geotechnical* and *Structures* chapter for design requirements.

Areas of construction shall be cleared, grubbed, and stripped. Areas disturbed by construction shall be protected by an erosion control system. Refer to Section 7.4 on Construction Site Best Management Practices (BMPs) for criteria and standards.

Construction of fills shall be a controlled fill. The method and device of construction and rework of existing soil shall be as recommended by the Designer.

Surface rainwater (and ground water, if applicable) flow shall be prevented from entering the trackbed. Elements of cut and fill trackway shall include earth or concrete intercept ditches on a top of a cut, on a face of a slope and between the trackbed and a slope, benches with a maintenance access and berms at the open drainage ditches. For additional drainage requirements, refer to the *Drainage* chapter.

Due to limited space, a portion of or the entire slope may be replaced by a retaining wall. The same requirements for preventing the surface rainwater/groundwater from entering the trackbed shall apply; therefore retained trackway shall include intercepting ditches and benches. Tiered retaining wall trackway shall include benches with construction and maintenance access. In retained trackway subgrade rainwater/groundwater shall be collected by a subdrain system. For additional drainage requirements, refer to the *Drainage* chapter.

Permanent erosion control for cut and fill slopes shall be provided after completion of earthwork.

Landscaping design shall comply with requirements of the *Stations* chapter.

Retaining walls that do not support the HST trackway shall be designed per Caltrans Standards or the authority having jurisdiction’s requirements, including requirements for weep holes.

7.3.1 Side Slopes

Design of cut and fill slopes shall be based on geotechnical evaluation of soil and materials for construction of embankment and geotechnical recommendations for slope stability, including steepness and depth/height of cut and fill slopes, height between tiers, use of filter fabric, required material compaction and other elements of cut and fill trackway.

Side slopes shall be as flat as available right-of-way permits, except that slopes flatter than 10 horizontal to 1 vertical shall not be used.

When the right-of-way is restricted:

- Cut slopes shall be 2 horizontal to 1 vertical, unless otherwise recommended by the soils report or the Geotechnical Engineer. The top of cut slopes, other than those in rock, shall be rounded between points, recommended 10 feet and minimum 2 feet on both sides of the intersection of the slope planes.

- Fill slopes for embankments shall be 2 horizontal to 1 vertical, unless otherwise recommended by the soils report or the Geotechnical Engineer. Where heights are less than 4 feet, slopes shall be 4 horizontal to 1 vertical or flatter. Slope rounding shall be used at the top of fill slopes in the same manner as prescribed for cut slopes.

7.4 Construction Site Best Management Practices

Areas of proposed construction shall be cleared, grubbed, and stripped. Construction Site Best Management Practices (BMPs) shall be applied during construction activities to reduce the pollutants in stormwater discharges throughout construction. SWPPP shall conform to the rules, regulations, and practices of the authority having jurisdiction. Designer shall refer to State Water Resources Control Board (SWRCB) for general permitting requirements.

Refer to the *Drainage* chapter for BMPs.

Refer to *Caltrans Standard Drawings* for erosion and sediment control standards.

7.5 Slope/Surface Protection Systems Best Management Practices

Surface protection includes permanent design measures that are used alone or in combination to minimize erosion from completed, yet non-vegetated (bare) surfaces. Vegetated surfaces may offer advantages to paved surfaces, including lower runoff volumes and slower runoff velocities, increased times of concentration, and lower cost.

Where site or slope-specific conditions would prevent adequate establishment and maintenance of a vegetative cover, hard surfacing shall be considered.

Vegetated surfaces shall consist predominantly of established native grasses and mixed shrubs.

Vegetated surfaces shall be established on disturbed soil areas after construction activities in that area are completed, and after the slope has been prepared. Vegetated surfaces shall only be considered for areas that may support the selected vegetation long-term.

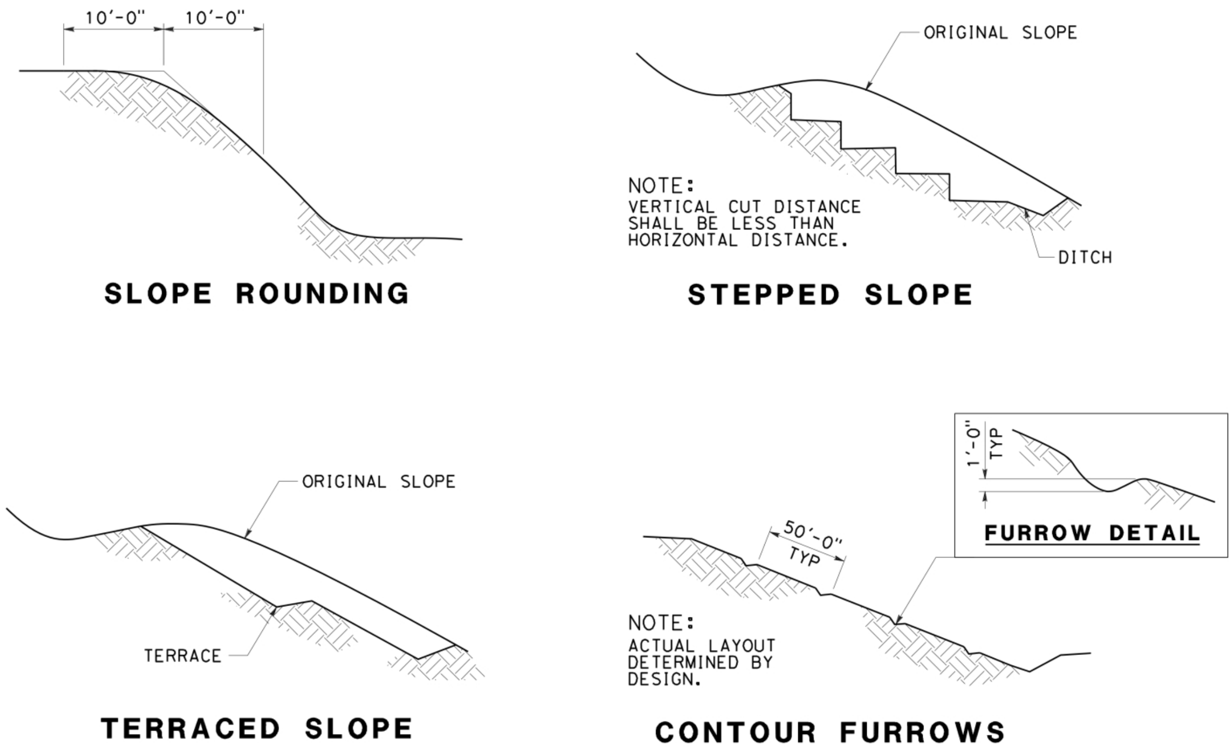
A rough surface may be added to a slope by various methods all of which run parallel to the slope contour over the entire face of the slope. The purpose of slope roughening is to prevent surface erosion that can cause downstream pollution by reducing the velocity of surface runoff. This BMP may also be considered a Low Impact Development (LID) technique.

Roughening and terracing are techniques for creating furrows, terraces, serrations, stair-steps, or track-marks on the soil surface. These treatments increase adhesion of erosion control materials and improve vegetation establishment.

Slope rounding is used to minimize the formation of concentrated flows; and used on embankment or cut slopes, prior to the application of temporary or permanent erosion control.

Slope roughening, terracing, rounding, and stepping, shall be implemented as shown in Figure 7-1.

Figure 7-1: Slope Rounding, Stepping, Terracing, and Contouring



7.6 Site Work – Non-Authority Facilities

Design of publicly and privately maintained facilities including roadways, sidewalks, driveways, traffic devices and signs not under the jurisdiction of the Authority, shall be in accordance with the applicable requirements of the authority having jurisdiction. Refer to the Structures chapter for loading requirements on roadways.

7.6.1 Roadways

At-grade Crossings – At-grade (level) roadway crossings of the HST trackway are prohibited and require the grade separation of existing crossings within the HST trackway.

Paving – Roadway pavement structural sections shall be designed in accordance with standards of the authority having jurisdiction. Restored pavements shall be of materials equivalent to that originally employed.

7.6.2 Traffic Control Devices

Design of traffic control devices, where roadway intersections are affected by the Authority's project shall conform to the following:

- Maintenance, relocations of traffic control devices, temporary or permanent, and restoration of these facilities shall be in accordance with the practices and requirements of the authority having jurisdiction and the Authority. Where the authority having jurisdiction has no standards, the *California MUTCD* shall be followed.
- Traffic signal design and details shall conform to the requirements of the authority having jurisdiction.
- Plans shall show location of new and existing traffic signal equipment and conduits.
- Designs shall be coordinated with the authority having jurisdiction maintaining the intersection.

Roadway Signing and Striping shall consider the following:

- The designer shall coordinate with the authority having jurisdiction to assure compatibility of street signing with HST construction staging.
- The designer's street striping and restriping plans may be subject to the approval of the authority having jurisdiction.
- Traffic striping, raised pavement markers, delineators, pavement legends, arrows and other markings installed as a part of the project shall be in accordance with *California MUTCD* or standards of the authority having jurisdiction.
- Work involving relocation, restoration, and temporary installation of street signing shall conform to *California MUTCD* or standards of the authority having jurisdiction.

7.6.3 Sidewalk, Driveways, Curb Cuts

Sidewalks – Sidewalks shall be in accordance with the standards of the authority having jurisdiction.

Driveways – Driveway minimum and maximum widths and numbers shall be in accordance with the standards of the authority having jurisdiction.

Curb Cuts – Ramps and Curb Cuts shall consider the following:

- Design of curb cuts and ramps shall be in accordance with the applicable provisions of the ADA and Title 24, CCR Part 2, "Regulations for the Accommodation of the Disabled in Public Accommodations."
- Ramps and curb cuts located in public spaces shall be obtained from the authority having jurisdiction and shall be in accordance with the ADA and Title 24.

7.6.4 Miscellaneous Facilities

Parking Meters – Removal, storage, restoration, and reinstallation of parking meters shall be in accordance with the standards of the authority having jurisdiction.

7.7 Site Work – Authority Facilities

This section establishes criteria and standards for the design of roadways, parking facilities, pedestrian facilities, and driveways, including signage, marking and striping, which are to be maintained by the Authority. Refer to the *Structures* chapter for vehicular load requirements on roadways.

Roadway design in public right-of-way shall be in conformance with the requirements of the authority having jurisdiction.

Additional criteria relevant to this section may be found in the following chapters:

- Trackwork
- Stations
- Drainage
- Geotechnical
- Tunnels
- Facility Power and Lighting Systems
- Overhead Contact System and Traction Power Return System
- Traction Power Supply System
- Communications

7.7.1 Authority Roadways

Authority Roadways shall meet the requirement of AASHTO " A Policy on Geometric Design Highway and Street", 2004, for Local Rural Road using vehicle type WB 50 and design speed of 30 mph in the level terrain and 20 mph in rolling and mountainous terrain.

7.7.1.1 Access Roads

Access roads are roads connecting public streets to access gates located along the perimeter fencing of HST trackway and Authority facilities.

Access roads shall be constructed at-grade on exclusive right-of-way where feasible.

Access roads shall be sized to permit access by first responders and fire department vehicles.

Access roads shall be provided to within 100 feet of tunnel portals and emergency entrances/exits. There shall be a vehicle turnaround area at each vehicle access point. Refer to the *Tunnels* chapter for tunnel portal site criteria. Traction Power Facilities shall be accessed by access roads. The road shall be designed to accommodate low-load type vehicles. Refer to the *Traction Power Supply System* chapter for additional site and access requirements.

Standalone Radio Sites shall be accessed by access roads. Refer to the *Communications* chapter for additional site and access requirements.

Interlockings shall be accessed by access roads.

Minimum roadway width shall consist of an 18-foot lane with 2-foot paved shoulders on each side. If a fire hydrant is located on road, the minimum width shall be 26 feet per California Code and Regulation, Fire Code.

7.7.1.2 Service Roads

Service roads are roads located within Authority right-of-way for the purpose of inspecting, servicing, and maintaining Authority property.

Service roads allow vehicle access to the various service areas to service trains and onsite equipment. Such roadways shall also serve as fire access roads. A service road or service aisle shall be provided between alternate tracks in yards. Refer to Section 7.7.8 for criteria on Service Aisles.

Minimum roadway width shall consist of an 18-foot lane with 2-foot un-paved shoulders on each side. If a fire hydrant is located on road, the minimum width shall be 26 feet per California Code and Regulation, Fire Code.

A. <u>Roadways for Rolling Stock Maintenance (RSM) Facilities and Maintenance of Infrastructure (MOI) Facilities</u>

Buildings within a facility shall be accessed by a service road.

A two-way service road, 24 feet wide with un-paved shoulders on each side, follows the interior perimeter of each facility.

For the RSM Facilities, a 50-foot wide asphalt "apron" would surround the main shop building to provide access for emergency vehicles to any point around the structure.

Yard traffic grade crossings for vehicles shall be concrete. Refer to the Trackwork chapter for criteria.

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7.7.2 Site and Roadway Geometrics

7.7.2.1 Grades

A. Parking Facilities

- General
  - 5 percent maximum slope in a parking stall
  - 6 percent maximum slope in a traveled area
  - 2 percent recommended slope in any direction
  - 0.3 percent minimum slope in any direction
- Comply with ADAAG regarding slopes at parking spaces and access aisles designated for accessible parking. Accessible parking spaces shall be located at an optimum location within the parking lot, to provide easy access to the station.
- Driveway Slopes and Ramps
  - 20 percent maximum slope on driveway or ramp
  - 10 percent maximum cross slope of a driveway or ramp
- Transition slopes are required when the slope of the driveway or ramps exceeds 12 percent.

B. Authority Roadways

- Maximum: 6 percent Recommended: 5 percent
- Minimum: 0.5 percent Recommended: 1 percent
- Cross-slope: 2 percent
- Crown cross-section except on curves where 2 percent continuous cross-slope toward center of curve may be used.

C. Maximum Grade Differential for Authority Roadways

- Crest Vertical Curve: 9 percent
- Sag Vertical Curve: 6.5 percent

NOTE: Crest and Sag Curves at top and bottom of ramps without parking may exceed these differentials, but shall use a vertical curve as per Section 7.7.2.4.

7.7.2.2 Design Speeds

A. Authority Roadways

- 30 mph in the level terrain and 20 mph in rolling and mountainous terrain.

B. Within Authority Facilities and Parking Facilities

- 10 mph

7.7.2.3 Clearances

Refer to the *Trackway Clearances* and *Utilities* chapters for additional criteria on clearances.

A. Authority Roadways

- Vertical, 14 feet–6 inches
- Horizontal, 2 feet–6 inches from face of curb to fences, light standards, and pedestrian barriers.

B. Parking Facilities

- Vertical, 7 feet–0 inches (with height restrictions noted)
- Minimum 9 feet–6 inches vertical clearance provided to van accessible parking spaces

7.7.2.4 Vertical Curves on Authority Roadways

Crest Curves - L_{min} = 28 A

Sag Curves -L_{min} = 35 A

Where:

L_{min} = minimum vertical curve length

A = Algebraic difference in grades

No vertical curves shall be less than 20 feet.

7.7.2.5 Sight Distance at Intersections

Site distance at intersections shall comply with "A Policy on Geometric Design of Highway and Street," current edition, published by the American Association of State Highways and Transportation Officials (AASHTO).

7.7.2.6 Curbs and Gutters

Curbs shall be 6-inch-high, barrier-type, with sloping face, Caltrans Curb Type A1-6.

Gutters shall be 24 inches, sloped to the cross-slope and grade of the roadway or parking area.

Curbs and gutters shall be cast-in-place concrete, and shall be in compliance with *Caltrans Standard Drawing and Specifications*.

7.7.2.7 Pavement

A. Roadbed Design

The roadbed cross-section (from top to bottom) shall consist of pavement, aggregate base, aggregate subbase, filter course, and subgrade material. The aggregate subbase course may be eliminated where the subgrade material has a Sand Equivalent of 20 minimum and a Resistance (R) Value in excess of 40 when tested in accordance with California Test Methods CT217 and CT301 respectively. The filter course shall not be eliminated.

- Pavement shall be dense graded asphalt concrete consisting of asphalt binder and close graded mineral aggregates, Caltrans Type A, unless otherwise required due to special conditions or use.
- Aggregate base shall be used under all pavements.
- Aggregate subbase shall be of a granular material conforming to the class designated..
- Filter course shall consist of one layer of filter fabric placed on the subgrade below the aggregate subbase course. The subgrade upon which the filter fabric is placed shall have been compacted to a relative compaction of 95 percent as determined by ASTM D1557.

B. Structural Design of the Roadbed

The required thickness of the individual layers making up the roadbed shall be determined from the following considerations and procedures:

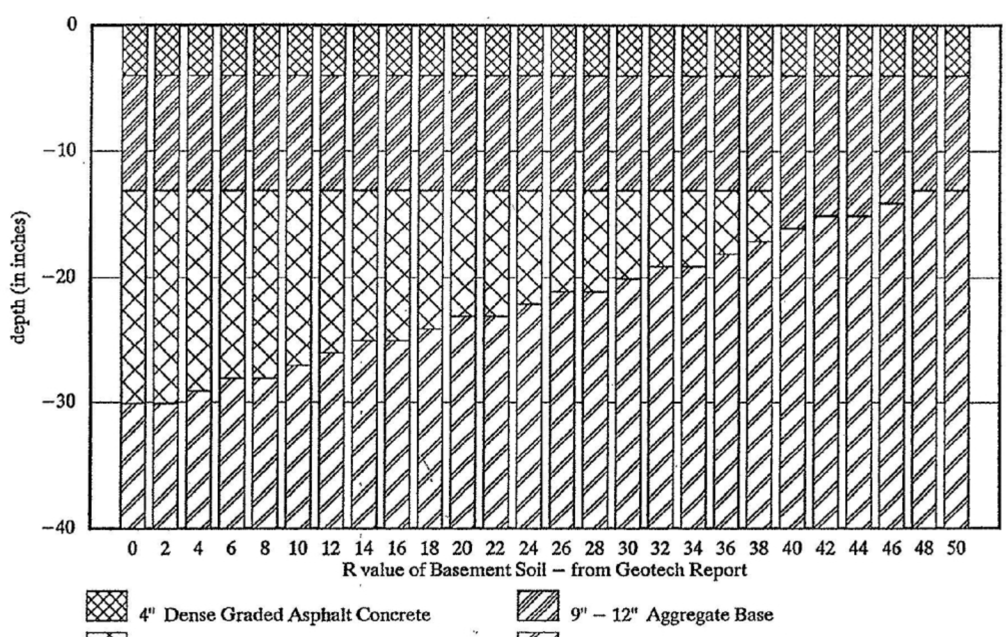
- For purposes of structural design of the roadbed only, the Authority Roadways shall be classified according to the character of traffic thereon as follows:
  - Type A Roadways – Roadways which will carry truck traffic, except those classified as Type C. Type A roadways may carry passenger car traffic.
  - Type B Roadways – Roadways which will carry only passenger cars.
  - Type C Roadways – Roadways having a low volume of traffic, on the order of not more than 25 cars or 5 trucks daily, which will be used for service or maintenance purposes, and are not intended for use by the general public. Bicycle paths shall also be classified as Type C.
- Structural design of the roadbed shall be in accordance with the procedure for design of flexible pavements in the *Caltrans Highway Design Manual, Chapter 630, Flexible Pavement.*
  - Traffic Indexes to be used shall be as follows:
    - 9.0 for Type A Roadways
    - 7.0 for Type B Roadways
    - 6.0 for Type C Roadways

- Additional gravel equivalent thickness for "Factor of Safety" called for in the Caltrans Highway Design Manual Empirical Method shall not be provided for the Authority designs.

- Structural design of the roadbed shall be reviewed and approved by the responsible Geotechnical Engineer.

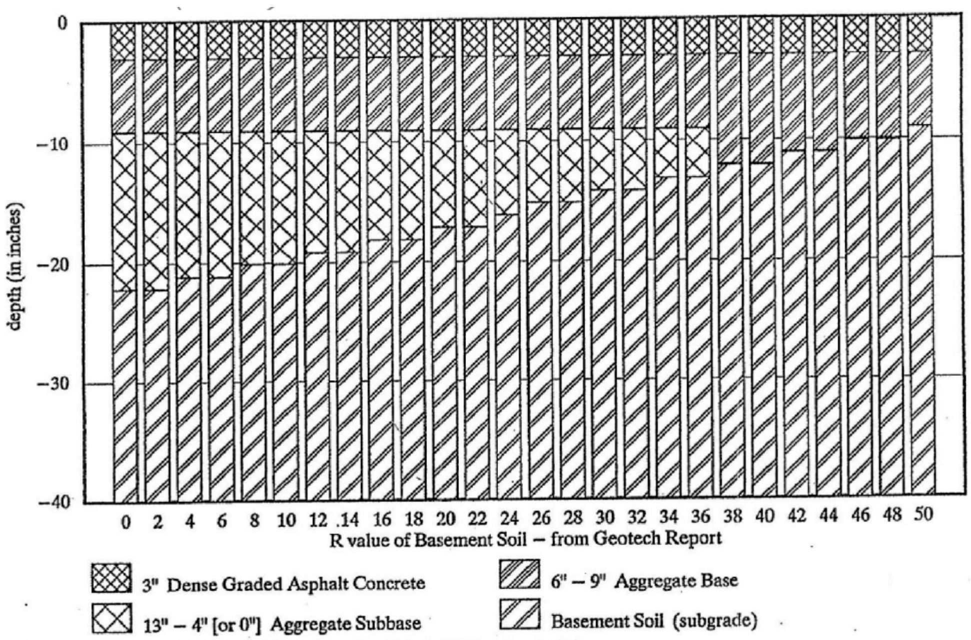
- Structural design of the roadbed shall be based on the use of Resistance (R) values, representing the structural quality of the subgrade material. The determination of the (R) value of a given material requires a soil test which shall conform to California Test Method (CTM) 301.
- The thickness of the individual layers of the roadbed shall be determined using data shown above. Preliminary thicknesses may be developed from following figures.

Figure 7-2: Type A Roadway - Thickness of Roadbed Layers Cars and Buses (TI = 9)



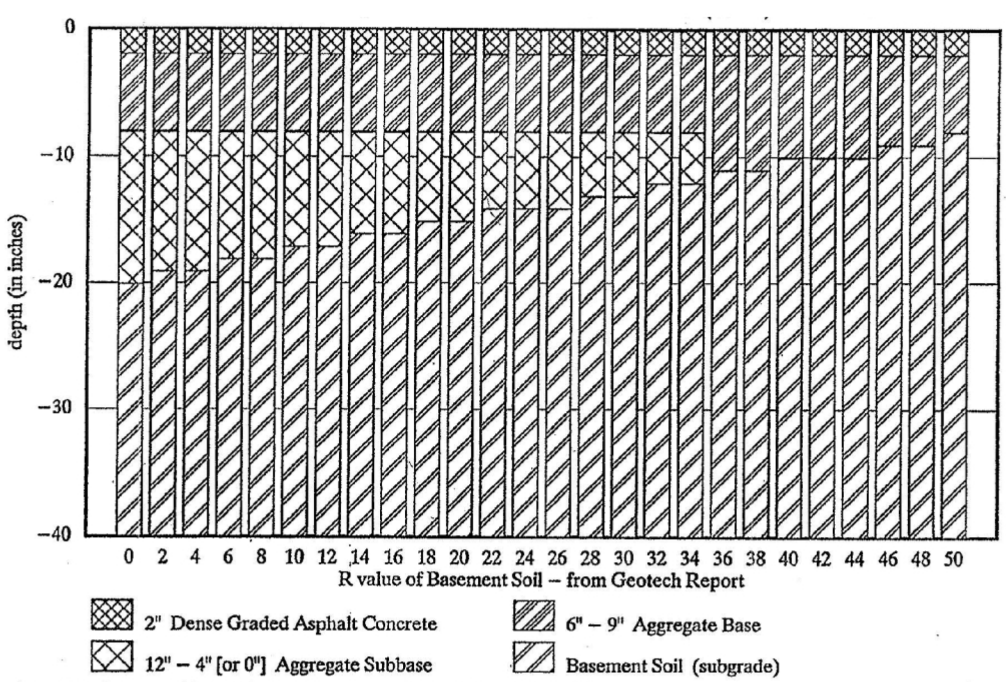
Based on Caltrans Highway Design Manual – July 1, 1990 – Topic 608
(without use of 0.20' factor of safety)

Figure 7-3: Type B Roadway - Thickness of Roadbed Layers Cars Only (TI = 7)



Based on Caltrans Highway Design Manual – July 1, 1990 – Topic 608
(without use of 0.20' factor of safety)

Figure 7-4: Type C Roadway – Thickness of Roadbed Layers Infrequent Maintenance Vehicles and Bike Paths (TI = 6)



Based on Caltrans Highway Design Manual – July 1, 1990 – Topic 608
(without use of 0.20' factor of safety)

- Variations in Design – In the application of these criteria, the designer shall consider variations in design where it is possible to obtain a more economical pavement section by adapting the design for local conditions.
- Where imported borrow is required over all or a portion of a site, it may be possible to substitute borrow for a portion of the required aggregate subbase depth. Imported borrow with resistance values as high as R=30 may be available within an economical haul distance with total cost less than that of aggregate subbase. Such materials shall be specified and the required pavement structural section adjusted accordingly.

C. <u>Other Paved Areas - Roadbed Design</u>

Parking lot roadbed, which includes parking areas as well as aisles and circulation roads, shall consist of the pavement, aggregate base, aggregate subbase, filter course, and subgrade.

Permeable pavements in parking lots shall be used when local conditions permit. Permeable pavement types may include: Porous asphalt, rubberized asphalt, pervious concrete.

Heat Island effect reduction at parking lot facilities shall require the use of paving materials with Solar Reflectance Index (SRI) 29 or higher.

Structural Design of Parking Lots and Bicycle Paths shall be as follows:

- Parking lots which will contain only passenger cars shall have the same roadbed layer thicknesses as prescribed for Type B roads. The results of nearby soils investigations may be used as a basis for determining the "R" value of the subgrade. Parking lots for vehicles other than passenger cars shall have an appropriate thickness of dense graded asphalt concrete.
- Bicycle paths immediately adjacent to the station shall be designed as Portland cement concrete sidewalks. Paths away from the station site area will generally be constructed of asphalt concrete. Most paths will be used occasionally by maintenance vehicles, and therefore will have a pavement structure equivalent to a Type C street.

Bus Pads shall be as follows:

- Concrete bus pads shall be provided at bus stops which are constructed or reconstructed in conformance with the standards and specifications of the authority having jurisdiction.
- Continuous concrete pads may be required in the vicinity of the station entrance when subject to heavy bus traffic or required by the authority having jurisdiction.
- For bus pad detail, refer to *Standard and Directive Drawings*.

Loading Zones for Buses and Taxis shall be as follows:

- The required bus (or taxi) design capacity for a station shall be determined based on the individual requirements for each station.
- Loading zones for buses and taxis shall be located to provide the most direct and safest intermodal transfer. Refer to the *Stations* chapter for additional intermodal criteria.

Standard Layout for Various Types of Bus Loading Zones – See bus bay dimensions on Figures 7-5 and 7-6. For additional design criteria refer to bus operator agency standards.

- Recessed Bus Bays – Where the volume of passenger cars or buses on roads used jointly by cars and buses warrants, the bus loading zone shall be recessed from the through traffic lane.
    - Recessed bus bays shall be designed parallel to and close enough to the curb so that passengers may enter and leave any door by an easy step to the curb. Upon leaving, the merging lane will enable the bus an easy re-entry into the through traffic lane.
    - The loading zone shall have a 10-foot-wide lane, and the total length for a two-bus loading area shall be 120 feet long with a 40-foot tapered section at each end. For each additional bus required, an additional 80 feet of length shall be added at curbside.
- Parallel-to-Curb Bus Bays – Parallel to curb base shall have 10-foot wide lanes and a length of 80 feet.
- Sawtooth Bus Bays – Sawtooth bus bays will reduce the length of loading zone, but will increase the width of roadway. The critical movement in this layout is the operation of moving a bus out and around a parked bus at the loading zone.
    - The minimum roadway width is determined as follows:

23 feet–8 inches	Clearance path of bus	= 29 feet–0 inches	Nominal roadway width
2 feet–0 inches	Additional clearance		
3 feet–4 inches	High point		

    - The nominal roadway width is the average of the high and low points of the sawtooth and allows a direct comparison with the parallel-to-curb bus bays.

Taxi zones shall have a minimum lane width of 8 feet. Parking spaces for taxis shall be 25 feet long and shall be no closer than 20 feet to a crosswalk.

Passenger Drop-off and Loading Zones for Disabled shall be as follows:

- Shall be a minimum of 20 feet in length of vehicle pull-up space

- Minimum 20 feet by 5 feet access aisle adjacent and parallel to the vehicle pull-up space
- Access aisle shall connect directly to an accessible route
- Minimum 114 feet vertical clearance at accessible drop-off and loading zones and along at least one vehicle access route to the zone
- The zone shall be signed “PASSENGER LOADING ZONE ONLY” and include the International Symbol of Accessibility in white on a dark blue background (CA Title 24 1131B.1)

Figure 7-5: Bus Bays

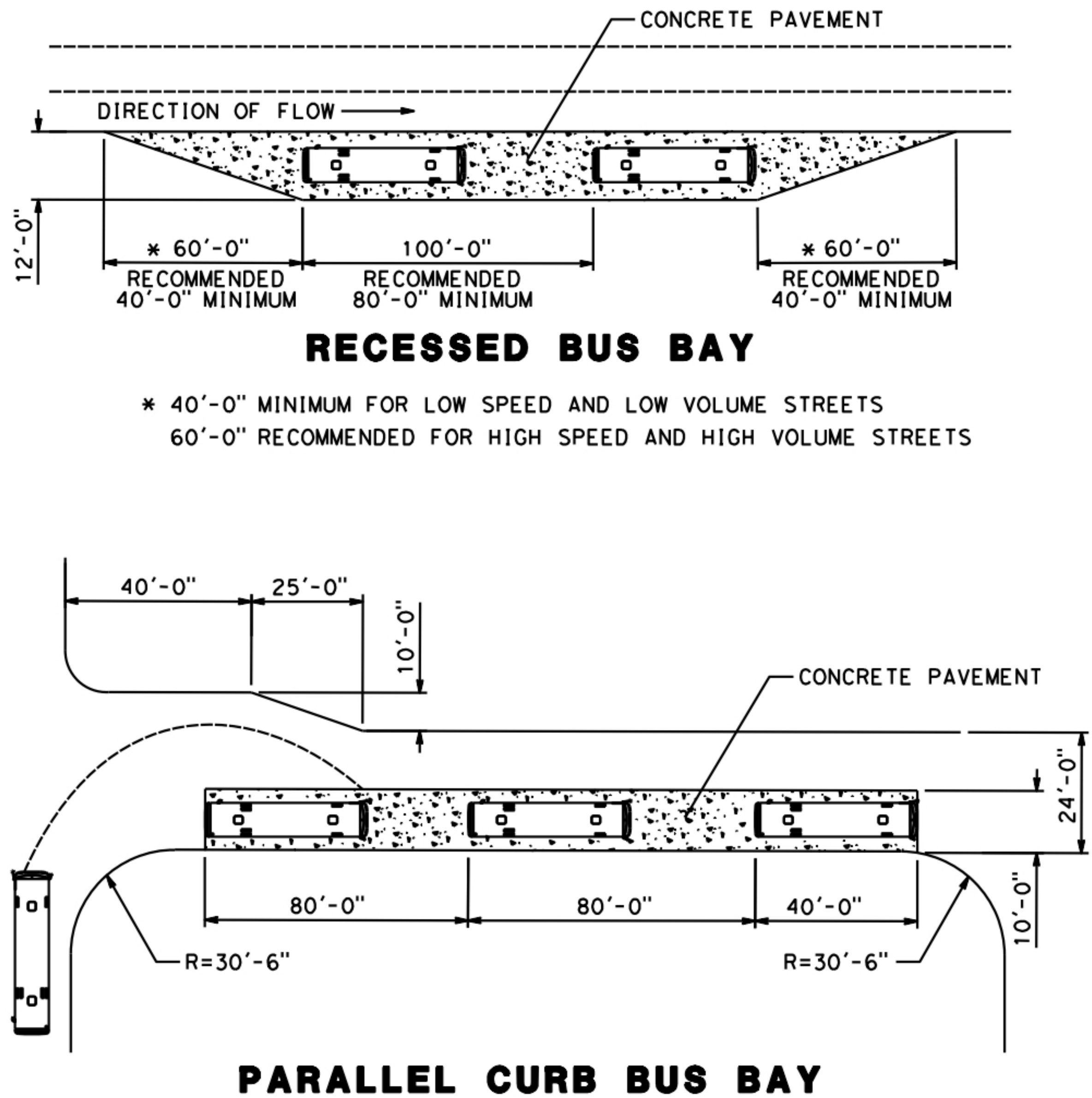
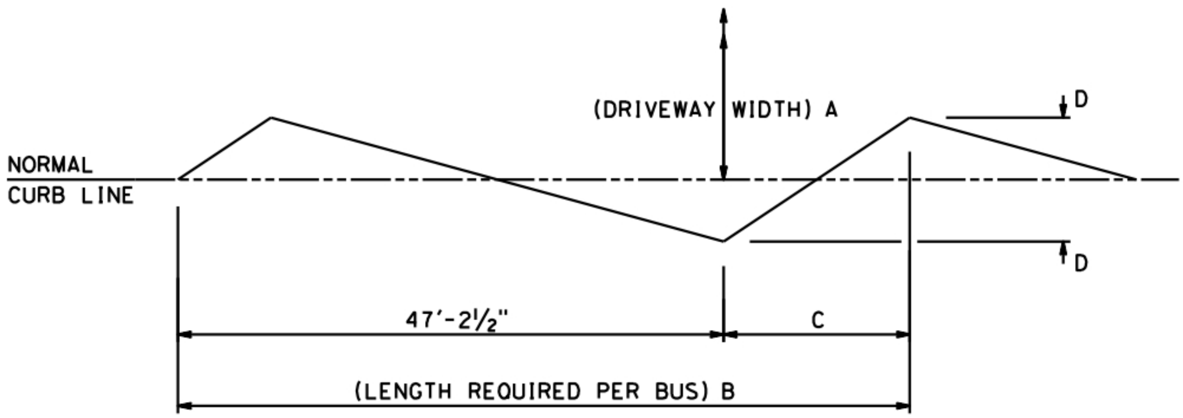
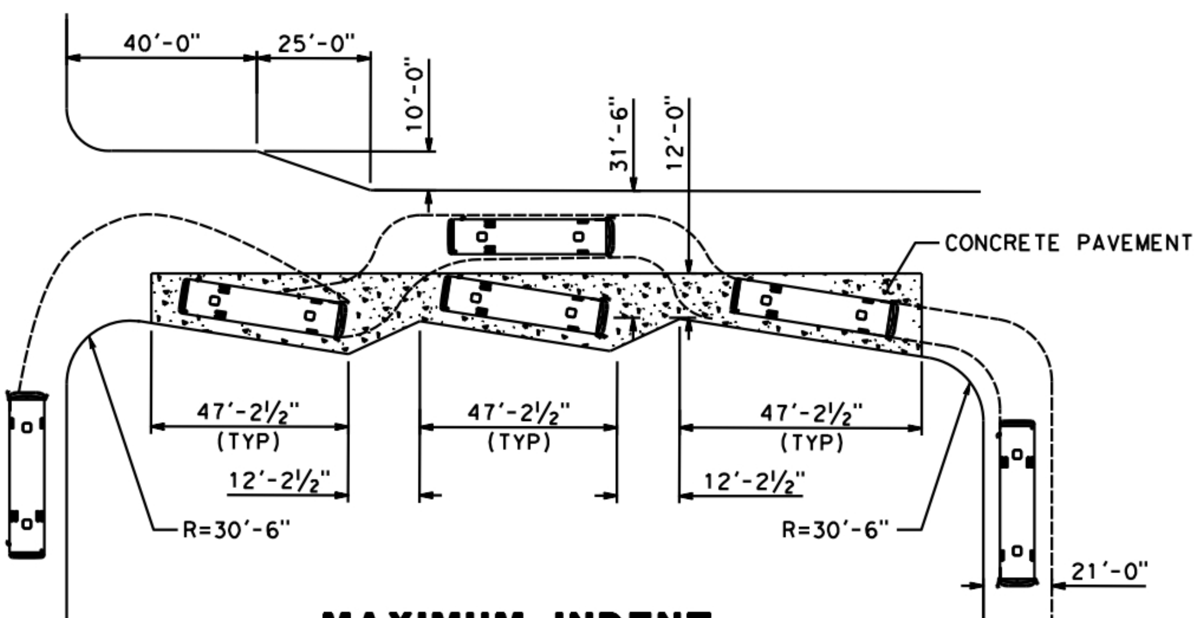


Figure 7-6: Sawtooth Bus Bays



A	24′	25′	26′	27′	28′	29′	31-6"
B	80′	76′	72′	68′	64′	60′	59′-5"
C	35′	31′	27′	23′	19′	15′	12′-½"
D	0′	0′-8"	1′-4"	2′-0"	2′-8"	3′-4"	8′-6"

BUS BAY DETAILS



MAXIMUM INDENT

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7.7.3 Traffic Control Devices

Curb markings, signs and striping used on Authority roadways and parking facilities shall be standard facilities as required by the latest edition of *California MUTCD*.

Traffic signing equipment, materials, and installation processes shall be as specified in the Caltrans Standard Plans and Caltrans Standard Specifications and CPUC GO 75-C.

Placement of signs shall be coordinated with actual site conditions to prevent masking or blocking of safety-sensitive signs.

Authority signage shall be provided at the entrance to the commuter parking area, and pathfinder signs shall be placed to provide directions from state highway routes.

7.7.4 Signage

This section refers to all signage other than traffic signs as noted in Section 7.7.3 on Traffic Control Devices.

Regulatory and safety, transportation, and maintenance of way signs and graphics shall meet the requirements of the applicable regulatory agency. The following types of signage shall be provided for the trackway and facilities:

- Location
  - Mile Post
  - Political Subdivision Signs
  - Standard Right-of-Way Sign and Monument Marker
  - No Trespassing Signs
- Maintenance-Of-Way
  - Maintenance Limit Signs
  - Roadway Structures Signs
  - Snowplow Signs
  - Alignment Signs or Markers
  - Elevation Markers
- Transportation
  - Speed Control Signs – Temporary and Permanent
  - Location Signs
- Safety
  - Restricted Clearance Signs

- Fire Hazard Signs
- Electrical Hazard Signs
- Highway Grade Crossing Signs *(To be used inside Maintenance Facilities)*
- Barricade Signs *(To be used inside Maintenance Facilities)*
- Highway and Barricade Signs
- Power Operated Switch Signs
- Warning Signs
- Directional Signs
- Identification

7.7.5 Parking

For parking lot design within the station area, the designer shall consider providing adequate designated parking stalls for car share, vans, low-emission vehicles, and security personnel. Security parking shall be located close to the station entrance.

For station parking meters and park and pay system requirements refer to the *Stations* chapter.

Table 7-1: Stall Dimensions (in feet)

Stall Angle		(Parallel)	45°	60°	90°
Stall Dimension					
Normal Car					
	width	9.0	9.0	9.0	9.0
	length	22.0	18.0	18.0	18.0
Disabled spaces					
	width	—	14.0	14.0	14.0
	length	—	18.0	18.0	18.0
Disabled Van Space					
	width	—	17.0	17.0	17.0
	length	—	18.0	18.0	18.0
Small Car					
	width	—	8.0	8.0	8.0
	length	—	15.0	15.0	15.0
Clear Aisle	width (Roadway)		13.0 (one way)	19.0 (one way)	27.0 (two way)

Note: Parking stalls at wayside facilities shall be angled at 90 degrees with 12 feet width by 18 feet length.

Disabled parking spaces shall be provided in accordance with Title 24, Part 2, Section 1129B, CCR (refer to *Caltrans Standard Plan Accessible Parking Off-Street*). Disabled parking spaces shall be located as near as practical to a primary entrance to a facility (building, station entrance, or boarding platform). The space shall be located so that a disabled person does not have to wheel or walk behind parked cars other than his/her own. Pedestrian ways shall be provided so as to ensure an accessible pathway from each such parking space to the facility; walks and sidewalks shall conform to Title 24, Part 2, Section 1133B.7.

When parking is provided for patrons, employees, or visitors, the minimum number of disabled spaces required is as follows:

Total Number of Parking Spaces	Number of Disabled Parking Spaces Required
1 – to 25	1
26 – 50	2
51 – 75	3
76 – 100	4
101 – 150	5
151 – 200	6
201 – 300	7
301 – 400	8
401 – 500	9
501 – 1,000	2% of total
1,001 – Over	20 plus 1 for each 100 over 1000

Note: One (1) Van Parking Space for every 8 disabled spaces

The requirements in Title 24, CCR, shall be met for other factors such as signage, minimum dimensions of accessible spaces, slope of parking surfaces, and entrances/vertical clearances for parking structures.

For motorcycle parking layout details, refer to *Standard and Directive Drawings*.

Parking structures shall be designed with "Crime Prevention through Environmental Design" principles, including clear lines of sight, well lit, and no areas where persons could secrete themselves or weapons.

For parking lot lighting and electrical charging station requirements refer to the *Facility Power and Lighting Systems* chapter.

7.7.5.1 Parking Facilities for Wayside Facilities

A minimum of 4 parking stalls shall be provided within the fenced area for maintenance personnel at ventilation structures and traction power facilities, unless otherwise indicated on the preliminary engineering documents.

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A minimum of 2 parking stalls shall be provided at Standalone Radio Sites.

Parking shall be provided, although not necessarily within fenced areas, for other wayside facilities.

7.7.5.2 Parking Facilities for RSM Facilities and MOI Facilities

A minimum of 150 parking spaces shall be provided in proximity to the facility for management and administrative personnel, visitors, deliveries, and priority parking.

Parking spaces shall be provided for 50 crew, 50 rolling stock preparations, and 150 yard support employees.

7.7.5.3 Multilevel Parking Structures

Ground levels shall contain entrances and exits, reservoir areas and internal ramps, and locations for obtaining parking tickets on entry and toll booths on exit, as well as parking areas. Kiss-and-Ride areas shall be located outside the parking structure unless this is not practicable. Upper levels and/or underground levels shall contain only ramps and as many parking stalls as possible.

Traffic circulation within parking structures shall be designed to minimize vehicular travel distances and number of turns. A left hand traffic pattern is preferred.

Columns shall be located to provide uniform spans for the structure as much as is practical. Columns shall not encroach on the clear dimensions noted for cars, unless a small-car stall may be created. Columns shall be located not closer than every third stall.

Where site conditions permit, adjoining street grades shall be used to minimize the need for ramps between parking levels.

Internal ramps shall be placed as far as practicable from entrances and exits. Internal ramps shall be designed for one-way travel. Parking stalls shall not be located on curved internal ramps.

External ramps may be used where appropriate. The ramps shall be designed for one-way travel and shall merge directly into or diverge directly from roadways. Where practicable, grade separation of pedestrians and vehicles shall be provided where external ramps cross pedestrian walkways. Parking stalls shall not be located on external ramps.

The design capacity of ramps shall be 200 vehicles per lane per hour.

Ramp grades shall be kept as low as practicable, and excluding areas of transition, shall not exceed 6 percent on ramps with parking or 12 percent on ramps without parking.

Traveled ways, other than parking aisles and ramps, shall be 24 feet wide for two-way travel and 16 feet wide for one-way travel. The minimum vehicular inside turning radius shall be 16 feet, and the minimum outside turning radius shall be 26 feet.

7.7.5.4 Kiss-and-Ride Facilities

Capacity – Designer shall determine required design capacity based on the individual requirements of each station.

Kiss-and-Ride facilities shall be in accordance with the following:

- Kiss-and-Ride facilities shall be located off-street, as near to the main station entrance as practical, and shall be physically separate from long-term parking areas. Loading is preferred on the right-hand side of the car. The location shall, if possible, be such that the driver may view the station entrance to see exiting passenger.
- An accessible parking area for persons waiting to pick up persons with disabilities shall be provided as required by installing appropriate pavement markings and signs.
- Kiss-and-Ride parking spaces shall be delineated by signs or curb markings as being limited to short-term use.
- Kiss-and-Ride parking stalls shall be 9 feet–6 inches wide and preferably at a 60-degree angle.

7.7.6 Sidewalks and Driveways

7.7.6.1 Sidewalks

Maximum cross slope shall be 2 percent, and match the elevation of existing building(s) finished floor elevation(s), flow away from the building(s).

Minimum slope shall be 0.5 percent.

Federal and State accessibility requirements shall be met for sidewalk areas behind and adjoining driveways, alley openings, and pedestrian ramps.

Minimum sidewalk width shall be 5 feet.

For design details, refer to *Standard and Directive Drawings*.

7.7.6.2 Driveways

Where Authority's driveways cross sidewalks which are under another authority having jurisdiction, the driveway/ sidewalk details shall be governed by the more stringent requirements of either the authority having jurisdiction or the Authority.

Driveway entrances which provide access to RSM Facilities and MOI Facilities shall normally be paved per *Caltrans Standard Drawing* details. This pavement shall be considered adequate for normal truck use and for infrequent overloads. Greater pavement thickness shall be provided where warranted by the volumes or type of traffic using the driveway.

7.7.7 Walkways and Cable Trough

This section addresses criteria for retained fill and at-grade walkways. For trench, aerial, and underground walkway criteria refer to *Structures* and *Tunnels* chapters.

For walkway structural loads refer to *Structures* chapter.

Continuous 3-foot minimum width walkway(s) shall be provided along the following:

- Two-track locations – There shall be one outside walkway on each side.
- Four-track locations (at stations) – With 2 outer station tracks, there shall be a walkway between the main tracks and the station tracks, along the intertrack fence next to the through tracks.
- Four-track locations – There shall be a walkway outside the outermost tracks only.

Walkways shall have a longitudinal slope not greater than one inch vertical to eight inches horizontal.

Walkways along tracks shall be the cable trough. The covers of the cable trough will form part of the walkway surface.

As the cable trough will also act as part of the emergency walkway they shall provide an even, stable walking surface without creating a tripping hazard and have a non-slip surface.

Cable trough shall be in conformance with the top surface of the sub-ballast or bearing base layer.

Cable trough will carry the train control, power, and communications cables required to operate the HST line. For dimensions and cable trough layout transition layouts, refer to *Standard and Directive Drawings*.

Cable troughs and connection boxes shall be drained. The drainage within the cable trough shall be provided to evacuate any percolated surface runoff. The water drained from cable troughs shall be properly diverted into the side drainage system. If drainage material is used for this purpose, the material shall meet the Terzaghi's filter criteria.

Walkway design layouts shall avoid "Dead ends".

For walkway envelope refer to the *Trackway Clearances* chapter.

Where walkways are adjacent to a wall exceeding 5 feet in height above the top of adjacent rail and more than 100 feet in length, the walkway shall be in conformance with top of the adjacent rail.

Yard walkways shall be paved, 5-foot wide located between yard tracks. Refer to *Standard and Directive Drawings* for additional guidance.

7.7.7.1 Stations

A. Walkways at End of Station Platform

The walkways shall provide access to the underside of vehicles and the refuge space below the platform.

The length of the lower walkway, not including ramps or stairs, shall be 70 feet.

For further guidance and standards refer to the *Stations* chapter.

7.7.8 Service Aisles

Each storage track in yards shall have service aisles for its entire length, from fouling point to fouling point or from end of track to fouling point.

Service aisles shall be continuous, connecting to non-public access roads.

Service aisles shall be paved and a minimum of 10 feet wide without obstructions.

Whenever possible service aisles shall be located between tracks and serve both adjacent tracks.

Service aisles shall be designed to meet all of the requirements of walkways, except as modified in this section. Refer to *Standard and Directive Drawings*.

No stairs shall be used on service aisles.

Service aisles shall not be located within public areas.

At-grade crossings shall be as follows:

- Service aisles at-grade crossings with yard tracks shall be avoided whenever possible.
- If an at-grade crossing is required for a service aisle, it shall meet all of the requirements for crosswalks.
- Service aisles crossings shall not be located on main track, nor on any track where the trains speed is in excess of 10 mph.

In areas where service aisles are used and a pedestrian crossing or a hi-rail vehicle access points exists on any track subject to automatic train operations or train speed is in excess of 10 mph, the pedestrian crossing or hi-rail access point shall be protected to prevent inadvertent use by carts. Protection shall be provided using bollards, stairs, fence, gate or other appropriate measure that will not interfere with its intended use.

Service and inspection walkways shall not be located closer to the track than the safe distance from the track for workers. Nominal distance from center line of track to walkway shall be 12 feet minimum in open air. The specific distance shall be determined following selection of rolling stock and in conjunction with the operating plan.

7.7.9 End-of-Line Walkway

Wherever it is determined by the Authority that service aisles are not required along end-of-line storage tracks, a 3-foot wide lighted and paved walkway, level with the top of tie, shall be provided for accessibility to each end-of-line storage track. A single walkway between tracks is preferred.

7.7.10 Cross-Walks

Cross-walks shall be provided along HST trackway, connecting the two outside walkways, at access and egress points.

Cross-walks shall be paved and a minimum of 8 feet wide.

7.7.11 Emergancy Stairs

For emergency stairs criteria refer to *Structures* chapter.

7.8 Access Control Devices

7.8.1 Access Control Devices

The entire Authority's right-of-way shall be protected at the property line with an anti-climb fence, wall or fence-wall, fence-traffic barrier or wall-traffic barrier combination to prevent unauthorized access by people, vehicles or animals. Refer to the *Overhead Contact System and Traction Power Return System* chapter for clearances and protection against electric shock.

7.8.1.1 Fences

Fencing shall be installed during construction as a means of protecting Authority properties. If temporary fencing is installed, it shall be replaced by permanent fencing prior to completion of construction.

Permanent fencing to be used is as follows:

- Access Restriction (AR) Fencing
- Access Deterring (AD) Fencing
- Station Area (SA) Fencing

Refer to the *Stations* chapter for Architectural fencing within the station site areas, including transitions to AR and AD fencing, and pedestrian and vehicle gates on station site.

A. <u>Access Restriction Fencing</u>

AR fencing is permanent fencing used to deny access to the HST trackway and to protect the Authority's property.

AR fences shall meet the following minimum material and height requirements.

Unless otherwise specified, fencing shall extend from ground level to a minimum height of 8 feet, consisting of minimum 7 feet of galvanized steel woven mesh or links (commonly known as chain link or cyclone fencing) secured at the top and bottom to galvanized pipe railing, topped by three strands of barbed wire, 12 inches high.

The barbed wire extension arm shall be placed inclined at a 45 degree angle away from Authority property. In areas where due to right-of-way, clearance, or other restriction, if the barbed wire arm cannot be placed at a 45 degree angle, it may be placed vertical.

Fence posts shall be cast into concrete footings, set into concrete retaining walls or set in rigid traffic barriers. Where a change in direction in the line of fence is 5 degrees or more, corner posts shall be installed and braced as shown on *Standard and Directive Drawings*.

AR fences shall be located inside the Authority's right-of-way within a distance of 1 foot from the right-of-way line with the barbed wire extension arms inclined away from the Authority's property.

Combinations of walls or barriers with chain link fabric and barbed wire with a total height of 8 feet measured from the highest ground surface adjacent to the fence or barrier may be used as AR fencing.

B. Access Deterring Fencing

AD fencing is permanent fencing used to deter access and/or prevent from passing through to areas that do not require a high degree of security. AD Fencing is primarily within Authority's right-of-way. AD fences may also be used in areas where the risk of trespassing is low, such as along aerial structures. AD fencing shall be 6 feet high, consisting of 6 feet of chain link fabric, secured at the top and bottom to galvanized pipe railing and no barbed wire. Fence posts shall be cast into concrete footings, set into concrete retaining walls or set in rigid traffic barriers.

C. Grounding of Fencing

Permanent fencing shall be bonded and grounded to prevent electric shock from induced voltage. Refer to the *Grounding and Bonding Requirements* chapter for additional details on the requirements for grounding of fences.

D. Vegetation Control along Fences

Vegetation along fenced areas of Authority property shall be controlled to assure that no large trees or shrubs provide access over the fence by people or animals. Fencing and trees, including branches, shall be kept apart a minimum of 5 feet. Refer to *Overhead Contact System and Traction Power Return System* chapter for vegetation clearance to electrical lines that supply power to the Authority system. Future growth of vegetation shall be considered when planning new landscaped areas.

7.8.1.2 Walls

Walls may be used to prevent intrusion by vehicles into Authority property. When appropriate, walls may be used in combination with fences at the following locations:

- Where there is vertical separation
- Where there is close proximity between the HST trackway and an adjacent transportation facility
- Between through tracks and station tracks to protect passengers and patrons at station platforms from the effects of noise and aerodynamic forces caused by passing trains.

Refer to the *Rolling Stock and Vehicle Intrusion Protection* chapter for vehicular intrusion protection.

7.8.1.3 Traffic Barriers

Traffic barriers may be required where the Authority right-of-way abuts public and private roads and highways and at highway overpasses where there is a potential of vehicles accidentally entering the Authority right-of-way. Traffic barriers used to protect HST trackway shall be Caltrans Standard traffic barrier of the following types:

A. <u>Traffic Barriers Types</u>

Traffic Barriers shall be either rigid or semi-flexible depending on the location as indicated herein. Refer to *Caltrans Standard Drawings* for installation and construction details. Refer to the *Rolling Stock and Vehicle Intrusion Protection* chapter and *Standard and Directive Drawings* for clearance requirements between Authority and Caltrans facilities.

- Rigid Traffic Barrier –Refer to the *Rolling Stock and Vehicle Intrusion Protection* chapter for types of rigid traffic barriers. When rigid traffic barriers are placed at Authority right-of-way, the barrier shall be used in conjunction with AR fences to prevent intrusion into HST trackway from adjacent roadways.
- Semi-flexible Traffic Barrier – Shall be used along service roads located within Authority right-of-way except when such roads are located in close proximity to any track in which the placement of barriers may compromise the trackway clearance envelope. Semi-flexible barriers shall be placed at the outside of curve as required by safety considerations, to delineate the roadway and maintain vehicles within the roadbed. Semi-flexible traffic barriers shall be Caltrans Metal Beam Guard Railing of the appropriate type for the local condition. Design and installation details for Metal Beam Guard Railing may be found in *Caltrans Standard Drawings*.

7.8.1.4 Fencing and Traffic Barriers in combination

AR fencing shall be located preferably 3 feet or more from the back side of a semi-flexible traffic barrier.

If 3 feet separation cannot be achieved, a rigid traffic barrier shall be used and fence height shall be increased by a height equal to the height of the barrier.

If AR or AD fencing is installed on top of a rigid barrier the combined height of fence and barrier shall not be less than 8 feet.

7.8.1.5 Gates

Gates with locking devices shall be provided along fenced areas to allow access to authorized personnel, emergency vehicles, and maintenance equipment.

Gates shall be constructed of the same material and height as adjacent fence and shall not decrease the level of security provided by the fences.

Gates shall be either swinging or sliding type. Sliding gates shall be utilized where swinging gates foul the walkway or vehicle envelope when opened. For gate details, refer to *Standard and Directive Drawings*.

Gate locations along fencing within freeway right-of-way shall require Caltrans approval.

Gate locations shall be coordinated with (i.e., placed adjacent to or near) the location of Authority wayside facilities requiring access from outside Authority right-of-way.

At aerial sections, access to the trackway shall be made from stations or emergency stairs or by mobile ladder equipment from roadways adjacent to the trackway. If no adjacent or crossing roadways exist, construction of access roads is required. Gates shall be provided along aerial structures at intervals of 2.5 miles nominal on either side of the trackway (not on both).

Emergency exits, rooms containing fixed equipments, corridors, stairwells and other controlled areas in at-grade, aerial, trench, and tunnel trackways shall have doors and/or gates with a lock system capable of preventing unauthorized access from outside and a release mechanism that makes it possible to open them from the inside for evacuation purposes.

For gate placement at communications, train control, and traction power facilities refer to *Standard and Directive Drawings.*

A. Grounding of Gates

Gates shall be bonded and grounded to prevent electric shock from induced voltage. Refer to the *Grounding and Bonding Requirements* chapter for additional details on the requirements for grounding of gates.

B. Walking Gates

Gates for personnel and equipment access (walking gates) shall have a minimum width of 4 feet.

For Traction Power Facilities, walking gates shall be 6 feet wide.

C. Driving Gates

Gates for vehicular access (driving gates) shall have a minimum width of 12 feet.

Gates along right-of-way fencing may require approval by the local fire protection authority having jurisdiction. For emergency responders vehicular access minimum gate width shall be 20 feet.

Driving swinging gates shall be a pair and shall be hinged from the inside. Provision shall be made for swinging gates to swing not less than 90 degrees away from Authority facilities.

Driving gates shall be provided in conjunction with either access roads or at locations where existing roads make it practicable for emergency vehicles to get to the trackway.

Along at-grade trackway, driving gates shall be located at 2.5 mile nominal intervals on either right-of-way side. When possible, access gates shall be staggered.

Driving gates shall be provided at traction power facilities. Minimum gate width shall be 20 feet.

Trackside access driving gates shall be provided at Authority facility locations. If this cannot be provided due to site constraints, an alternative method of providing vehicular access to the trackside from the Authority facility shall be submitted to the Authority for review and concurrence.

Table 7-2: Access Control - Gates

Type of HST Trackway	Nominal Gate Spacing Interval
At-Grade, Unretained Fill, and Unretained Cut	2.5 miles
Aerial	2.5 miles
Retained Fill (Embankment) or Retained Cut	2.5 miles

7.8.1.6 Fence Signage

Fencing shall be provided with signs warning of hazards from operations, high voltage electrical installations, and any other relevant hazards, at any location where the public may reasonably be expected to approach the right-of-way.

Signs bearing the words “Danger”, “High Voltage Lines” and “Keep Away” in letters at least 3 inches in height, shall be installed at intervals of not more than 500 feet along each fence enclosing the rights–of–way, at every gate and at each station or passenger loading platform, at a height between 5 and 6 feet from the finished ground outside Authority property. The signs may carry other information relative to the hazard present, but the three required phrases

("Danger", "High Voltage Lines", and "Keep Away") shall be in type of larger size than the type of the additional items.

Signs bearing the message "No Trespassing" in letters of at least three 3 inches in height, and including the California Penal Code section number for trespassing in smaller letter size, shall be installed at a minimum, every 500 feet, at a height between 5 and 6 feet from the finished ground outside Authority property.

Signage shall be consistent throughout the Authority system.

7.8.2 Access Control by Type of HST Trackway

Access to non-public Authority property shall be controlled by installing perimeter fences along the right-of-way with locked gates to allow access and egress of maintenance and emergency personnel.

Within the vicinity of a passenger station the right-of-way fencing shall be installed to guide the passengers to the designated platform entrances and to prevent unsafe shortcut to the platform.

7.8.2.1 At-Grade Trackway

AR fencing shall be provided continuously along each side of at-grade trackway sections, including transitions to underground or aerial sections. Fence construction shall be designed, installed and maintained in such manner as to deny access over, under or through the fencing to unauthorized persons. The Authority system shall have no at-grade public road crossings or at-grade crossings of other rail systems.

AR fences shall be located at 1 foot within the Authority's right-of-way line.

7.8.2.2 At-Grade Trackway within Highway Corridor

A combination of AR fence and an appropriate rigid traffic barrier shall be constructed along the Authority right-of-way when it is at-grade, runs parallel and adjacent to a highway traffic lane, including locations where the trackway shares a common corridor in a highway median.

The AR fence shall be located inside Authority right-of-way at a minimum distance of 1 foot from the Authority right-of-way line.

The rigid traffic barrier shall be located within the Authority right-of-way at a minimum distance of 1 foot outside of the AR fence. The traffic barrier shall have a minimum height of 4 feet–6 inches above the highway grade level and be site specific per the *Rolling Stock and Vehicle Intrusion Protection* chapter.

7.8.2.3 At-Grade Trackway Adjacent to Conventional Railroad

Protection against accidental intrusion shall be provided where a HST trackway is in close proximity to a conventional railroad corridor. Refer to the *Rolling Stock and Vehicle Intrusion Protection* chapter for additional requirements.

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7.8.2.4 At-Grade Trackway through High-Risk Trespassing Areas

Special consideration shall be given to areas determined to have a high-risk of trespass such as, but not limited to, HST trackway adjacent to parks, playgrounds, schoolyards, highly populated urban areas or areas within the pathway to and from any of these places, which require a higher degree of security. An 8-foot high AR type fence shall be required at these locations. The surface under the fence shall be paved to prevent undermining.

7.8.2.5 Trackway in Cut or Fill (Embankment) Section

AR fencing shall be used for HST trackway along embankment and cut sections. AR fences shall not be placed on the slope surfaces of the cut or embankment sections.

When the HST trackway section is in cut, AR fences shall be located at a distance from the top of slope:

- Recommended 10 feet
- Minimum 3 feet

When the HST trackway section is on embankment, AR fences shall be located at a distance from the toe of slope:

- Recommended 10 feet
- Minimum 3 feet

7.8.2.6 Trackway on Aerial Structure

At abutments of aerial structures, AR fencing from adjoining sections shall be continued beyond the abutment to a point where the soffit of the structure is 10 feet or more above the natural ground line. At that point, the right-of-way fences on each side of the aerial structure shall be joined under the aerial structure.

Where the ground level is less than 10 feet below the underside of the structure, aerial structure sections shall be protected with AR fencing located 2 feet from the drip-line of the structure. Fencing is not required under an aerial structure where the right-of-way adjoins property which is already fenced in a manner consistent with these criteria.

Fencing is not required on aerial structure except at abutments. It generally is not required to control access under aerial structures.

Emergency access to the trackway shall be from stations or emergency stairs or by mobile ladder equipment from roadways. If no adjacent or crossing roadways exist, access at maximum 2.5 mile intervals shall be provided.

Area around the columns and foundations shall remain accessible for 10 feet (minimum) outside of the foundation limits.

7.8.2.7 Trackway on Retained Fill

Retained fill trackways shall have at least one vertical wall exceeding 5 feet in height measured from finished surface along the non-trackway side of the wall.

AR fencing shall be installed on top of retaining walls along retained fill sections on the following conditions:

- When retaining walls are located at the right-of-way line along HST trackway and the adjacent land outside Authority property is less than 10 feet <u>below</u> the top of the wall. Refer to *Standard and Directive Drawings* for fence details.
- When the concrete barriers are located on the right-of-way line, adjacent to a HST trackway.
- The combined height of the wall or traffic barrier and fence above the adjacent ground outside the Authority right-of-way shall be not less than 8 feet, including wall, chain link fabric and 1 foot of barbed wire.

Where a retaining wall is within the right-of-way line, security fencing shall not be placed on top of the wall. Railing shall be required along the top of wall for fall protection, refer to the *Structures* chapter.

Fencing between at-grade and retained fill sections shall be continuous.

Where a retaining wall is used as support for both fencing and poles supporting lights, overhead contact system (OCS), or signs, the open space between the fence and the pole shall be less than 4 inches. Refer to *Overhead Contact System and Traction Power Return System* chapter for OCS safety barrier requirements.

Emergency access to retained fill trackway shall be from stations or emergency stairs or by mobile ladder equipment from nearby roadways. If no adjacent or nearby roadways exist, access roads shall be constructed in coordination with the locations of wayside facilities requiring access or at not more than 2.5 mile intervals.

7.8.2.8 Trackway on Retained Cut (Open)

Retained cut trackways are defined as trackways having at least one of its vertical walls exceeding 5 feet in height measured from the top of rail.

AR fencing shall be installed on top of retaining walls or rigid traffic barriers along retained cut sections on the following conditions:

- When retaining walls are located at the right-of-way line along HST trackway and the adjacent land outside Authority property is less than 10 feet above the top of the wall. Refer to *Standard and Directive Drawings* for fence details.
- Concrete barriers located adjacent to a HST trackway on the right-of-way line.

The combined height of the wall or traffic barrier and the fence above the adjacent ground outside the Authority right-of-way shall be not less than 8 feet, including wall, chain link fabric and 1 foot of barbed wire.

Where a retaining wall is well within the right-of-way line, security fencing shall be located in accordance with other requirements and shall not be placed on top of the wall. Railing shall be required along the top of wall for fall protection, refer to the *Structures* chapter.

Fencing between at-grade and retained sections shall be continuous.

Where a retaining wall is used as support for both, fencing and poles supporting lights, OCS or signs, the open space between the fence and the pole shall be less than 4 inches.

7.8.2.9 Trackway Underground (Bored, Mined, and Cut-and-Cover Tunnels)

Where at-grade sections adjoin underground sections, the right-of-way AR fencing shall extend beyond the portal by a minimum of 30 feet where possible and be continuous across the right-of-way at that point.

Where the minimum of 30 feet cannot be achieved because of physical constraints or an adjacent public way, the fencing shall extend across the right-of-way at the point of constraint.

Authority property above underground sections of HST trackway shall be protected in accordance with these criteria and the facility and/or use of the land above ground. If the use of the land above ground has not been defined and no facility has been constructed, perimeter AD fencing with gates is recommended to prevent undesirable use of the property.

Table 7-3: Access Control Fencing – Trackway

High-Speed Train Infrastructure	Fence Type AR	Walls / Barrier, Other
At-grade	✓	
At-grade adjacent to Roadways	✓	✓(1)
At-grade within Highway Corridor	✓	
At-grade adjacent to Conventional Railroad		✓(1)
At-grade through High Risk Trespassing Areas	✓	
Sloped Cut or Fill (Embankment) Section	✓	
Aerial structure	✓	
Retained Fill	✓	✓
Retained Cut (Open)	✓	✓
Underground (Bored, Mined and Cut-and-Covered Tunnels)	✓	

(1) Use of walls and barriers for intrusion protection shall be made in conjunction with site-specific risk assessment.

7.8.3 Access Control by Type of Facility

This section prescribes right-of-way fencing for wayside facilities such as yards, maintenance facilities, train control, communications, and traction power facilities.

7.8.3.1 Yards and Maintenance Facilities

AR fencing with vehicular and pedestrian access gates equipped with locking devices shall be installed along the perimeter of Authority facility.

7.8.3.2 Train Control, Communications and Traction Power Facilities

Train control, traction power facilities, and communications equipment locations shall be either fenced with AR fencing or an 8-foot high wall enclosure with secured gates.

Where there is public access or trespass is likely, anti-climbing protection shall be provided at buildings and other structures supporting energized parts of the OCS. The anti-climbing protection shall include signs warning of the dangers of high voltage. Access to fixed ladders, particularly at signal poles and signal gantries, and the means of access to any roof or other place which could allow non-authorized persons to approach energized parts, shall be secured or otherwise protected.

For fencing placement and further requirements at OCS, Communications, Train Control and Traction Power Facilities refer to the *Traction Power Supply System, Overhead Contact System and Traction Power Return System, Communications,* and *Automatic Train Control* chapters.

7.8.3.3 Passenger Station

Station area fence shall be installed along the right-of-way within the vicinity of a station platform to prevent unsafe shortcuts to the platform and to guide passengers to the designated station entrances. Refer to the *Stations* chapter for station area fence standards.

A. <u>Limits of Platforms</u>

Station area fences with locked gates shall be installed at the ends of station platforms, along the sides of platforms perpendicular to the tracks, to prevent unauthorized access to the trackway.

B. <u>Inter Track Fencing or Protection Screens (Walls)</u>

Inter-track fences or protection screens (walls) shall be provided between through track and station track or between adjacent tracks at station platforms for the full length of the platforms and at least 150 feet beyond each platform end. Inter-track fence shall be station area fence, 6-foot height to discourage climbing and prevent people from passing through. For track spacing refer to *Trackway Clearances* chapter and for additional criteria on protection screens refer to *Stations* chapter.

Table 7-4: Access Control Fencing – Authority Facilities

High-Speed Train Infrastructure	Fence Type		Walls / Barrier, Other
	AR	AD	
Yard and Maintenance Facilities	✓		
Train Control and Traction Power Facilities	✓		
Passenger Stations	✓		
• Limits of Platforms			✓[1]
• Inter-Track Fencing / Protection Screens			✓[1]
Parking Structures		✓	

[1] Station Area Fence

7.8.4 Access Control at Other Locations

7.8.4.1 End of Line and Storage Tracks

End of line tracks and end of storage tracks that extend from the station tracks, shall be protected with AR fencing located at the following:

- One (1) foot minimum distance from the Authority right-of-way line in the direction parallel to the tracks, and
- Two (2) feet minimum distance from the right-of-way side of the bumping structure in the direction perpendicular to the tracks.

7.8.4.2 Roadway Overpasses Crossing HST Trackway

Where HST trackway is traversed by a motor vehicle overpass, the overpass shall be provided with a combination of rigid traffic barrier and modified AD fencing. In addition, a protective screenbarrier shall be installed on top of traffic barriers and may be secured to the modified AD fencing above the HST trackway to prevent people from reaching out and contacting the OCS wires. For protective screen barrier requirements refer to the *Overhead Contact System and Traction Power Return System* and *Grounding and Bonding Requirements* chapters. For further roadway vehicle containment requirements, refer to the *Rolling Stock and Vehicle Intrusion Protection* chapter.

Modified AD fencing at roadway overpasses with sidewalk shall be constructed with a curved top to prevent the throwing of objects onto HST trackway. The minimum height of the modified AD fence shall be 8 feet. Refer to *Standard and Directive Drawings*.

7.8.4.3 Streets Ending at HST Trackway

A rigid traffic barrier shall be installed at the end of dead-end streets, cul-de-sacs, or "T" intersections adjacent to at-grade segments of HST trackway. The barrier length and height shall be sufficient to intercept all possible vehicular paths from within the traveled way of the approaching street.

Case 1 – Where the longitudinal grade of the streets dead-ending at HST trackway is 2 percent going down towards Authority property, the barrier shall be a minimum of 4 feet–5 inches above the street surface at the barrier.

Case 2 – Where steep grades and close proximity of the track require a substantial physical barrier against runaway vehicles, the barrier shall consist of an 18-inch thick reinforced concrete wall. The top of the barrier shall be from 4 feet–6 inches to 6 feet above the street surface at the barrier. Design drawing for these concrete walls shall be submitted to Authority for review and concurrence.

7.8.4.4 Authority Roadways

If conditions along areas of the Authority roadways dictate installation of traffic barriers, semi-flexible traffic barriers shall be installed, provided that the location of such barriers do not obstruct the clear pathway from walkways to emergency exits or encroach into the clearance envelope of any Authority facility.

Access roads and service roads are not required to be protected with fence.

7.8.4.5 Emergency Exits and Equipment Rooms in Tunnels

Emergency exits, rooms containing fixed equipments, corridors, stairwells, and other controlled areas in tunnels shall have doors and/or gates with a lock system capable of preventing unauthorized access from outside and a release mechanism that makes it possible to open them from the inside for evacuation purposes.

For additional systemwide criteria on securing exits refer to the *System Safety and Security* chapter.

7.8.4.6 Drainage Structures

Where drainage requires passage under fenced areas of Authority properties it shall be achieved using enclosed pipe or culverts. Open ditches crossing under fenced property of the Authority shall not be allowed unless the ditch concrete lined and the open section of the ditch is protected by steel welded grid as shown on *Standard and Directive Drawings*.

HST trackway over culvert structures shall be protected with AR fencing. In addition, culverts connected to open channels where there may be risk of access to the underside of HST trackway shall be protected with grates installed upstream and downstream at the culvert headwalls. Grates shall have bars spaced 6 inches apart and shall be strong enough to withstand maximum impact from largest expected floating debris.

For culvert structure sizing refer to the *Drainage* chapter.

Table 7-5: Access Control Fencing – Other Locations

High-Speed Train Infrastructure	Fence Type		Walls / Barrier, Other
	AR	AD	
End of Line and Storage Tracks	✓		
On Highway Overpasses Crossing HST		✓[1]	✓
Streets Dead-Ending at HST Trackway • HST trackway is 2% going down towards Authority property		✓	✓
• Steep grades and close proximity of the track		✓	
Access Roads			✓
Service Roads			✓
Emergency Exits and Equipment Rooms			✓
Drainage Structures			✓

[1] Modified AD fence, refer to Section 7.8.4.2.

7.9 Wildlife Crossing

Authority facilities shall be designed and constructed such that wildlife movement corridors are preserved and do not create a barrier to wildlife movement corridors in the area.

Refer to Final Environmental Impact Statement, Section 3.7 Biological Resources and Wetlands for identified wildlife movement corridors that need to be preserved and mitigations measures to follow.

The mitigations measures to be incorporated as a project design feature include: wildlife corridor undercrossing, wildlife fencing, and wildlife artificial dens.

7.10 Maintenance and Protection of Traffic during Construction

For the duration of the CHSTP construction, every effort shall be made to minimize the interruption of surface traffic, be that pedestrian and vehicular, adjacent to, and/or over the construction site.

Access provisions for the following shall be maintained within construction zones:

- Emergency services and emergency vehicles
- Local access to businesses and residences

Temporary interruptions to business and residence access shall be coordinated and agreed to with the local authority having jurisdiction.

7.10.1 Vehicular Traffic

Where portions of the roadway are closed due to construction activity, suitable detours shall be arranged.

Traffic maintenance shall be coordinated with and is subject to approval by the authority having jurisdiction.

Design shall include the following:

- Traffic staging and detours necessary to assure proper maintenance of traffic.
- Roadway and sidewalk areas of temporary decking for the duration of construction. The designer shall seek Authority's direction for the height and profile of temporary streets and sidewalks.

7.10.1.1 Traffic Lanes

The minimum width of vehicular traffic lanes for maintenance and protection of traffic during construction shall be in accordance with the requirements of the authority having jurisdiction over the roadway.

Vehicular traffic lanes adjacent to construction activities shall be 16 feet wide, which is inclusive of sufficient width for installation of temporary concrete railing (i.e., K-rail) and required buffer next to the temporary concrete railing. All other traffic lanes for vehicles shall be 12 feet wide unless required otherwise by jurisdictional authority.

7.10.2 Pedestrian Traffic

Pedestrian access to adjacent buildings on sides of the construction area which are not accessible from other streets shall be maintained at all times. The minimum width of the access sidewalk shall be 4 feet.

Sidewalks along the construction site shall be maintained at all times.

7.10.3 Railroad Operations

Construction activities affecting surface transportation, including freight or other rail operator, shall be planned and scheduled in cooperation with the relevant authorities/agencies. Temporary structures for the support and maintenance of surface traffic adjacent to and/or over the construction site shall be designed and constructed in accordance with prevailing codes, standards and regulations and are subject to review and concurrence by the local authority having jurisdiction and the Authority.

During construction, interruption of, and interference with passenger and freight rail operations shall be avoided unless otherwise approved by the authority having jurisdiction. Wherever possible, the design and the sequencing of the construction activities shall allow for such uninterrupted railway operations.

Chapter 8

Drainage

HSR 13-06 - EXECUTION VERSION

Revision	Date	Description
0	02 Mar 12	Initial Release, R0
0.1	Dec 2012	EXECUTION VERSION

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Acronyms

AREMA	American Railway Engineering and Maintenance-of-Way Association
Authority	California High-Speed Rail Authority
BMP	Best Management Practice
Caltrans	California Department of Transportation
FHWA	Federal Highway Administration
HDM	Highway Design Manual
HDS	Hydraulic Design Series
HDPE	High-Density Polyethylene
HEC	Hydraulic Engineering Center
HST	High-Speed Train
IDF	Intensity-Duration-Frequency
PVC	Polyvinyl Chloride
RCP	Reinforced Concrete Pipe
RWQCB	Regional Water Quality Control Board
SWDR	Storm Water Data Report
SWPPP	Storm Water Pollution Prevention Plan
USBR	United States Bureau of Reclamation

8 Drainage

8.1 Scope

This chapter provides design criteria for the hydrologic analysis and design of hydraulic facilities and provides guidelines for hydraulic facility implementation and for Best Management Practices (BMPs) for surface water quality treatment.

Unless otherwise noted, design guidance shall follow California Department of Transportation (Caltrans) Highway Design Manual (HDM) requirements for hydrologic analysis and hydraulics design. Regional criteria shall be used to determine surface water runoff data. Refer to the *General* chapter of this design manual for design life requirements for storm drain structures.

Locations where the California High-Speed Train (HST) alignment crosses existing drainage channels, drainage requirements for roadways and other structures located in or adjacent to the California High-Speed Rail Authority's (Authority's) right-of-way, may be subject to regulations and additional requirements by other jurisdictions. Supplemental hydrologic and hydraulic requirements shall be considered for drainage facilities owned or operated by third party rail operators/agencies, and property owners impacted by these improvements. Design requirements of local municipalities shall be considered for discharge within those jurisdictions. Where a drainage facility is required to connect to a third party drainage facility, the designer shall coordinate with the utility owner to determine if an upgrade to the existing facilities may be required.

8.2 Regulations, Codes, Standards, and Guidelines

Refer to the *General* chapter for requirements pertaining to regulations, codes, and standards. Regulations, codes, and standards, such as but not limited to the following, shall be the one applicable.

- California Public Utility Commission (CPUC) General Orders (GOs)
  - CPUC GO 95 - Rules Governing Overhead Electric Line Construction
  - CPUC GO 128 - Rules for Underground Electric Construction
- California Department of Transportation (Caltrans)
  - Caltrans Highway Design Manual (HDM), English Version
  - Caltrans Standard Plans and Standard Specifications
  - Caltrans Bridge Design Specifications (CBDS)
  - Caltrans Storm Water Quality Handbook: Project Planning and Design Guide

- Federal Highway Administration (FHWA), Hydraulic Design Series (HDS)
- U.S. Army Corps of Engineers
- U.S. Bureau of Reclamation (USBR)
- U.S. Bureau of Land Management
- Federal Emergency Management Agency (FEMA)
- American Railway Engineering and Maintenance-of-Way Association (AREMA) Manual for Railway Engineering
- American Association of State Highway and Transportation Officials (AASHTO)
  - Highway Drainage Guidelines
  - Model Drainage Manual
- Applicable Local Ordinances

Applicable local building, planning, and zoning codes and laws shall be reviewed for facilities, particularly those located within multiple municipal jurisdictions, state rights-of-way, and/or unincorporated jurisdictions.

8.3 Policies

- CHSTP shall not adversely impact the existing 100-year floodplain of the area adjacent to the HST corridor.
- Ensure Critical HST structures/facilities are protected against 100- and 500- year flood events.
- Comply with regulatory requirements.
- Contain drainage within the Authority’s right-of-way.
- Keep run-off from outside the Authority’s right-of-way from entering into the Authority’s right-of-way.
- To the extent that is reasonable and practical, avoid placement of third party drainage access points from within the Authority’s access controlled right-of-way.

8.4 Hydrological Analysis

Hydrologic criteria shall conform to several standards, codes, guidelines, and applicable software. The criterion for each factor involved in hydrologic analysis to obtain optimum runoff

calculations is proposed in this section. For criteria not included in this section, references shall be used as follows:

- Caltrans HDM for rainfall hydrological analyses
- FHWA HDS-02 for criteria not found in Caltrans and for snowmelt analyses
- *General* chapter of these Design Criteria for design rainfall information

8.4.1 Time of Concentration

The time of concentration (T_c) shall be used to determine approximate rainfall intensity. The time of concentration is the sum of two travel times, including sheet flow/overland flow and shallow concentrated flow, usually in a gutter, swale or channel.

The minimum time of concentration recommended in urban areas is 5 minutes and in rural areas is 10 minutes. For gutter, pipe and channel flow, Manning's equation shall be used, per Section 8.5.2.

The Caltrans HDM Hydrology chapter shall be referenced for detailed methodologies on T_c calculation.

8.4.2 Intensity

Intensity is defined as the time rate of rainfall depth and is commonly given in inches per hour. The time of concentration depends on an initial estimate of an intensity value found from Intensity-Duration-Frequency (IDF) curves. IDF curves shall be obtained from local agencies or Caltrans for the most current and accurate information.

8.4.3 Design Storm Frequency/Recurrence Interval

Frequency establishes the frame of reference for how often precipitation with given characteristics is likely to occur. The design storm frequencies for the design of various storm facilities shall be as presented in Table 8-1.

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Table 8-1: Design Storm Frequencies

Storm Facility	Rural	Urban
Drainage facilities crossing the track (e.g., culverts)	2% (50-yr) [1]	1% (100-yr) [1]
Drainage facilities not crossing the track (e.g., parking lots, access roads, station drainage facilities)	10% (10-yr) [1]	2% (50-yr) [1]
Ditches/storm drainage systems adjacent to the track	4% (25-yr) [1]	2% (50-yr) [1]
Freeways – Minor Ramps and Frontage Roads	10% (10-yr) [2]	
Conventional Highways – High volume, multilane or urban with speeds 45 mph and under		
Freeways – Through traffic lanes, branch connections, and other major ramp connections	4% (25-yr) [2]	
Conventional Highways – High volume, multilane or low volume, rural with speeds over 45 mph		
All State Highways	2% (50-yr) [2]	
Drainage systems crossing under bridge structure and on the right-of-way	2% (50-yr) [1]	1% (100-yr) [1]
Critical HST Structures/Facilities	Min 0.2% (500-yr) [3]	Min 0.2% (500-yr) [3]

Notes:

[1] Based on Standard Engineering practices employed by other railroad operators within State of California.

[2] Caltrans HDM, Table 831.3 shall be referred to for Roadway Drainage Guidelines.

[3] For Critical HST Facilities, see Section 8.6.7.

8.4.4 Snowmelt

For run-off calculations in areas where snowmelt may occur, refer to the FHWA HDS-02 Hydrology report.

8.4.5 Storm Runoff

Storm run-off shall be calculated in accordance with criteria and methodologies specified in the Caltrans HDM's Hydrology chapter and the applicable local procedures.

8.4.6 Floodplain Information

The proposed elevation of the track subballast (bottom) shall be a minimum of 2 feet higher than the 100-year Base Flood Elevation. Drainage facilities located within a floodplain shall be designed so that the proposed improvements will not:

- Increase the flood flow rate or inundation hazard to adjacent upstream or downstream property
- Raise the flood level of drainage way
- Reduce the flood storage capacity or obstruct the movement of floodwater within a drainage way

Refer to the Caltrans HDM General Aspects chapter, for FEMA guidelines, where encroachment on floodplains is anticipated.

8.5 Hydraulic Design

8.5.1 Basic Parameters

8.5.1.1 Discharge of Storm Drains into Local Drainage System

Discharge of storm water from trackway sections, station sites, parking lots, and wayside facilities into local drainage system shall comply with environmental and regulatory permit requirements. Appropriate mitigation measures to prevent pollutants shall be taken as required before site drainage is discharged into local drainage system.

8.5.1.2 Debris Control

Debris may consist of trash, natural streambed material such as boulders, silts, sands, clays, sticks, tree limbs and other vegetation. Buoyant material will float during a storm event and other materials will roll or skip along channel bed. The frequency of the storm event will affect the quantity of debris that is carried along the channel; the more discharge in the channel will result in more debris carried.

Debris control shall be considered as a significant factor during the design of hydraulic structures such as catch basins, culverts, storm drain systems and outlet structure from detention basins. Depending on the type of debris and location where the debris is controlled, there are several debris control structures such as debris racks, debris risers, debris cribs, and debris fans. The type and quantity of debris shall be determined and an appropriate debris control measure shall be implemented.

8.5.1.3 Access Control

For drainage structure access control requirements, refer to the *Civil* chapter.

8.5.1.4 Grounding and Corrosion Control

All metallic pipes and appurtenances shall be grounded and protected against corrosion control. Refer to the *Grounding and Bonding Requirements* chapter and the *Corrosion Control* chapter for requirements.

8.5.2 Channel Hydraulics

8.5.2.1 Open Channel Hydraulics

This section presents the minimal criteria and design standards for the hydraulic evaluation and design of open channels. For criteria not included in this section, references shall be used as follows:

- AREMA's design criteria shall be followed for design of new open channels.

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- Refer to Caltrans HDM for design criteria not available in AREMA, and for existing open channels.
- Local criteria shall be followed as required by the governing agency.

Transverse channels that pass through culverts shall join parallel ditches at an angle of approximately 30 degrees to minimize aggradations and deposition.

A. Open Channel Flow

The computation of uniform flow and normal depth are based on Manning's formula:

$$Q = \frac{1.49}{n} A R^{2/3} S^{1/2}$$

Where:

Q = Flow Rate (cfs)

n = Roughness Coefficient [(1)]

A = Flow Area (feet^2)

R = Hydraulic Radius, A/P, (feet)

P = Wetted Perimeter, (feet)

S = Slope of the Energy Grade Line, (feet/feet)

Notes:
(1) The Caltrans HDM Physical Standards chapter shall be referred to for Manning's roughness coefficients.

B. Maximum Permissible Velocity

Open channel flow velocities shall not erode nor cause deposition in the channel. For maximum permissible velocities of unlined channels refer to the Caltrans HDM. The maximum permissible velocities for lined/non-erosive channels are presented in Table 8-2:

Table 8-2: Maximum Permissible Velocities for Lined/Non-Erosive Channels

Type of Lining	Maximum Permissible Velocity (feet per second)
Unreinforced vegetation	5.0
Loose riprap	10.0
Grouted riprap	15.0
Gabions	15.0
Soil-Cement	15.0
Concrete	35.0

Source: Clark County Regional Flood Control District, Hydrological Criteria and Drainage Design Manual, August 1999.

C. Freeboard

Freeboard is the vertical distance above the design water surface elevation and the bottom of subballast or bottom of a bridge girder/soffit. The minimum freeboard required for track side ditches shall prevent saturation and infiltration of storm water into the subballast and ballast sections of the track. The minimum recommended water depth in any channel section shall be 2 feet below the bottom of subballast or bottom of a bridge girder/soffit.

For superelevation requirement on curved open channel alignment for water surface elevation, refer to the Caltrans HDM.

D. Grade Control

If the ditch grade is steeper than the grade that results in maximum permissible velocities, drop structures shall be considered to maintain design velocities, and prevent erosion and scour to the channel bed and embankments. To mitigate sediment aggradation and degradation, a drop structure may be installed across a channel to create a vertical drop or a short sloping drop. Drop structures may be built with gabions, sheet piling, riprap, or concrete walls with footings.

E. Channel Section

Selection of a channel cross-section may involve changing/improving the existing natural waterway (channel) or designing a new channel section. Where feasible, the channel section is preferred to have a flat bottom.

Changing a natural channel – Existing hydraulic conditions of a natural channel shall be assessed to confirm channel stability and evaluate the impact of proposed improvements. Natural waterways shall have adequate capacity to pass the flows from a design storm event. The stream mechanics shall be studied to analyze the need for erosion control structures.

Design of new channel section – The first estimation of a channel cross-section is based on normal depth plus freeboard. The shape of the channel shall consider terrain, flow velocity, available right-of-way for the corridor, and quantity of flow to be conveyed. Channels shall be sized for the anticipated design runoff and to allow the subballast to drain. Open channels

along the toes of trackway embankments shall be designed with sufficient depth to carry the peak flow with design water surface elevation below the bottom of subballast.

Hydraulic parameters of basic channel sections are provided in Table 8-3. For trackside ditch details, refer to Standard and Directive Drawings.

Table 8-3: Hydraulic Parameters for Channel Sections

Channel Section	Area (A)	Wetted Perimeter (P)	Hydraulic Radius (R)
Triangular V-ditch	zy^2	$2y\sqrt{1+z^2}$	$\dfrac{zy}{2\sqrt{1+z^2}}$
Trapezoidal	$(b+zy)y$	$b+2y\sqrt{1+z^2}$	$\dfrac{(b+zy)y}{b+2y\sqrt{1+z^2}}$
Rectangular	by	$b+2y$	$\dfrac{(by)}{(b+2y)}$

Where:

b = base of rectangle or base of trapezoidal

z = side slope of trapezoid or V-ditch

y = depth of flow in channel

F. Channel Lining

Channel lining is the key factor that determines the roughness coefficient of a channel. The most commonly used channel materials are:

Grass lined channel (vegetative lined) – Grass linings provide protection to the channel from erosion. Due to the frequent maintenance involved, grass lined channels are not recommended within the Authority's right-of-way. They may be used as a best management practice for storm water quality control where pollution prevention devices are required. Grass lined channels shall not be designed with side slopes steeper than 3:1 (H:V).

Riprap lined channel – Riprap lining is suitable for a short but steep channel reach. The nature of high friction of rocks contributes to the effectiveness of energy dissipation. Riprap channels may be considered where right-of-way is constrained and/or erosion occurs.

The roughness coefficient, n, of a riprap channel is correlated to the intermediate riprap rock size, D_{50}, in feet.

$$n = 0.0395\, D_{50}^{1/6}$$

Where:

n = Roughness, (non-dimensional)

The criteria for sizing of D_{50} and thickness of riprap lining shall be as follows:

- D_{50} (maximum) = 24 inches
- Thickness of riprap lining = $2*D_{50}$
- Thickness of riprap lining shall be 50 percent more for water deeper than 3 feet.

Concrete lined channel – Concrete lining shall be designed to withstand various forces due to high gradient. Criteria for design of concrete lined channels include the following:

- Thickness of concrete lining = 6 inches for V < 30 feet per second
- Thickness of concrete lining = 7 inches for V > 30 feet per second
- Channel section shall be adjusted for superelevation changes in water surface.
- Side slopes shall be a maximum of 2:1 (H:V), or a structurally reinforced wall if steeper.
- A concrete cutoff wall shall be provided at both the upstream and downstream termini.

Composite channel – Composite channels shall be considered where the open channel shall have the hydraulic capacity to handle a wide spectrum of storm events. Due to the maintenance level involved, composite channels are not permitted within the Authority's right-of-way but may be designed outside the Authority's right-of-way where floodplain mitigation and/or pollution prevention/mitigation measures are required. The channel cross-section shall be designed to have two sections: the lower section or the main channel, usually shallow, narrow and has a hard bottom, with a side slope ranging from 0.5:1 (H:V), to 2:1 (H:V) and an overbank section usually wide, flat and grass lined, with mild slopes of 10:1 (H:V).

Composite channels may be designed for more specific purposes such as low flow channels, trickle channels and wetland channels.

8.5.2.2 Overside Drains

Overside drains are used to prevent erosion of embankments and other steep-sloped surfaces by collecting surface runoff and conveying it to a stable or less erosive drainage facility. Water conveyance at cut slopes or fill slopes are generally erosive and are more likely to need an overside drain. The spacing of overside drains shall consider on the quantity of flow in the existing gutter or ditch, ground configuration and capacity limitations in the existing channel.

For cut slopes, the angle of the existing slope shall be considered for overside drain slopes. The drain shall be sized to convey a larger storm, so that the drain is not washed out following a major storm event. Rock riprap shall be considered to minimize the velocity, but may need a wire mesh to prevent rock slippage.

Fill slopes may require the use of overside drains. For roadways, curb openings will generally allow flow to discharge down an embankment into an open channel. Ditch openings or small spillways may be used to alleviate water from trackside drainage ditches. Riprap material and an aesthetic design shall be considered.

Water from overside drains shall not be diverted to watersheds that originally did not contain the water, or negatively affect downstream properties.

Overside drains may be designed as pipe downdrains, flume downdrains and spillways as follows:

- Pipe downdrains – Usually made of plastic or metal material, pipe downdrains are recommended for slopes of 4:1 (H:V) or steeper and a minimum diameter of 8 inches. When overside drains are designed in areas where sediment debris is likely and the drain is expected to be longer than 50 feet, a larger pipe size shall be considered to minimize clogging in the pipe. Overside drain pipes shall be buried along the corridor, or designed to blend with the existing natural landscape.
- Flume downdrains – Generally rectangular in shape, flume downdrains are open channel chutes that can discharge water at steeper grades, 2:1 (H:V) or steeper. The flume invert shall be below surface grade so that the flume is even with the surface slope. Sharp bends in the flume are not permitted.
- Spillways – Asphalt concrete is typically used to create a spillway on slopes flatter than 4:1 (H:V). Spillways are most commonly V-shaped and shall be placed on compacted soil to prevent further erosion. Sharp turns are not permitted to prevent splash over of discharge.

Grate inlets may be used in cases where a depression in not feasible. Outlet velocities shall be mitigated by use of energy dissipators.

8.5.2.3 Underdrain System

Underdrains shall be located in areas where it is anticipated that groundwater may interfere with the stability of tracks, roadbeds and side slopes. The underdrain system helps to draw the water table down, preventing softening of sub grade soils, sloughing, or instability of slopes. The utilization of underdrain pipes shall consider subsurface conditions and geotechnical studies focusing on infiltration and percolation recommendation. Underdrain pipes shall be bedded in clean, granular or crushed aggregate material enclosed in an envelope of non-woven geotextile fabric. For criteria not included in this section, references shall be made to Caltrans HDM design criteria for underdrain systems within roadways or highways.

A. Pipe Size

Underdrain pipe shall be a minimum of 6 inches in diameter for segment length less than 500 feet and a minimum of 8 inches for segment lengths over 500 feet. A minimum 6-inch PVC pipe shall be used to carry the water from underdrain system to an onsite drainage system or to the municipal storm water system..

B. Location

Underdrains shall be used in the following locations:

- Under ballast in ballasted trackway which does not naturally drain towards the outside of the trackway, to intercept ground water and trackbed surface drainage infiltration through the ballast
- Along the toe of a cut slope to intercept seepage
- Along the toe of a fill on the side from which groundwater emanates
- Across the track or roadway at the downhill end of a cut
- Along the periphery of any paved area under which groundwater is likely to collect
- In retained cuts and on retained embankments
- Under the track slab at station platforms
- Between tracks at locations of outside station platforms and or where several sets of tracks are adjacent
- At low points in the profile, and 100 feet each side of a low point

C. Pipe Material

Underdrain pipes shall be perforated type and installed with perforations pointing down towards the bottom of the trench. Underdrain pipe shall be made of porous concrete, steel, aluminum, corrugated metal, rigid plastic, or polyethylene. For track drainage at stations and at-grade sections, perforated PVC or high-density polyethylene of schedule 80 shall be used.

D. Access Holes/Cleanouts and Risers

Access holes/cleanouts for underdrains shall have convenient access for maintenance crews and equipment. Cleanouts for underdrain systems shall be spaced at a maximum of 300 feet. Pipe materials for cleanouts to be used within trackway shall be plastic with metal risers. Risers shall be provided at beginning of underdrain runs and at a maximum of 300-foot intervals. For track drain/underdrain cleanout and riser details, refer to Standard and Directive Drawings.

E. Cover

Underdrain pipes shall have a minimum cover of 36 inches from the top of finished grade.

F. Depth and Spacing

Underdrain depth and spacing shall consider the permeability of the soil, the elevation of the water table and the amount of drawdown and time needed to ensure stability. Depth and spacing of underdrains shall be as follows:

Table 8-4: Suggested Depth and Spacing of Pipe Underdrains for Various Soil Types

Soil Class	Soil Composition			Drain Spacing (feet)			
	Percentage Sand	Percentage Silt	Percentage Clay	3 feet Deep	4 feet Deep	5 feet Deep	6 feet Deep
Clean Sand	80-100	0-20	0-20	110-150	150-200	-	-
Sandy Loam	50-80	0-50	0-20	50-100	100-150	-	-
Loam	30-50	30-50	0-20	30-60	40-80	50-100	60-120
Clay Loam	20-50	20-50	20-30	20-40	25-50	30-60	40-80
Sandy Clay	50-70	0-20	30-50	15-30	20-40	25-50	30-60
Silty Clay (1)	0-20	50-70	30-50	10-25	15-30	20-40	25-50
Clay (1)	0-50	0-50	30-100	15 (max)	20 (max)	25 (max)	40 (max)

Source: Caltrans HDM, Table 842.4.

Notes:

(1) Drainage blankets or stabilization trenches shall be considered.

G. Slope

Underdrain grades shall be not less than 0.5 percent. If 0.5 percent is not feasible, a slope that would provide a minimum velocity of 2 feet per second shall be provided in the full pipe condition.

H. Separation of Underdrain Systems

Design of underdrain systems shall consider separation of drainage flows:

- Pipes carrying surface water shall not discharge into underdrains. Surface water shall also be prevented from seeping into underdrains other than those provided to collect trackbed surface drainage.
- Where underdrains are located under trackbeds or paved areas, other than sidewalks, the filter material and filter fabric shall extend up to the top of prepared subgrade.
- Where underdrains other than those provided to collect trackbed surface drainage are located under unpaved areas or sidewalks, the filter material shall extend up to 6 inches below finished grade and the filter material shall be covered with impervious backfill material.

8.5.2.4 Energy Dissipators

Where the anticipated outlet velocity for a waterway exceeds the maximum permissible velocity for the bed material of the receiving channel, an acceptable means of energy dissipation shall be used to reduce the velocity to safe limits. Commonly used energy dissipators include natural scour holes, drop structures, internal dissipators, external dissipators, and stilling basins. These facilities decrease the chance of a hydraulic jump as well as erosion/scour.

This section presents the minimal criteria and design standards for the hydraulic evaluation and design of energy dissipators. For criteria not included in this section, references shall be used as follows:

- Refer to Caltrans HDM for design criteria of energy dissipators on highways and freeways.
- Local criteria shall be followed as required by the governing agency.

To permit debris to be carried with the flow, dissipators employing obstructions shall be avoided unless it can be demonstrated that such obstructions will not collect debris.

A. Natural Scour Holes

This option consists of providing an area in which flows through the culvert will be allowed to form a natural scour hole. Scour holes shall be lined over an area sufficient to cover the potential scour hole with the class of riprap appropriate for the culvert exit velocity.

Natural scour holes are recommended as follows:

- Undermining of the culvert outlet will not occur or it is practicable to be checked by a cutoff wall.
- The expected scour hole will not cause costly property damage.
- Right-of-way or drainage easements at the site are sufficient to encompass the entire scour hole which may often be quite large.
- Environmental concerns due to sedimentation will not be a factor.
- There are no aesthetic concerns or other nuisance effects, such as insect breeding.

B. Drop Structures

Inclined or sloping drop structures – Where the difference in elevation from the upper channel bottom to the lower channel bottom is 10 feet or lower, these drop structures shall be used. The top of the crest wall shall be placed at a height above the upstream channel bottom. A downstream apron shall be provided to transition from the drop structure to the downstream channel.

Vertical drop structures – A vertical drop structure is designed to force the hydraulic jump to occur within a stilling basin next to a rectangular weir. When the flow line of the channel is too steep for the design condition, erosion and scour may occur to the channel bottom or the toe of the embankment. To mitigate sediment aggradation and degradation, a drop structure shall be considered. The drop structure shall have sufficient length and water cushions to prevent scouring of the downstream channel bed due to a nappe or hydraulic jump.

Material – The material used to construct the drop structure depends on the availability of materials, the height of drop required, and the width of the channel. Rock riprap and timber pile construction have been successful on channels having small drops and widths less than 100

feet. Sheet piles, gabions, and concrete structures are generally used for larger drops on channels with widths ranging up to 300 feet.

C. Internal Dissipators

Containing the hydraulic jump within the culvert is a form of internal energy dissipation. Internal dissipators shall be used where the scour hole at the culvert outlet is unacceptable, the right-of way is limited, debris is not a problem and moderate velocity reduction is needed. The three types of internal dissipators are tumbling flow, increased resistance, and broken back culverts.

Tumbling flow (roughness elements) – Tumbling flow may be applicable where culvert slopes are between 10 percent and 15 percent. Tumbling flow in culverts shall be the following:

- Use 5 rows of uniformly sized roughness elements in box culverts or open chutes
- Spacing (L) between the roughness element rows is set by choosing a ratio of L/h to be between 8.5 and 10, where h is the height of the element.

Increased resistance – Increasing resistance may cause a culvert to change from partial flow to full flow in the roughened zone. Velocity reduction is accomplished by increasing the wetted surfaces as well as by increasing drag and turbulence by the use of roughness elements. Increased resistance shall be used where a culvert is flowing partially full with inlet control and the requirement for outlet velocities is between critical and normal. The following criteria shall be followed for increased resistance design on culverts:

- Shall be used where slopes of culverts are less than 4 percent
- Five rows of roughness elements may be used.
- Height of element shall be 5 percent to 10 percent of the diameter.

Broken-back culverts – Substituting a "broken-slope" flow line for a steep, continuous slope in a culvert may be used for controlling outlet velocity. The steep slope of the culvert is replaced by breaking the slope into a steeper portion near the inlet followed by a horizontal runout section. Broken-back culverts, at minimum, shall have the following:

- There shall be sufficient tailwater and sufficient friction and length in the runout section of the culvert.
- Steep sections for which slope shall be less than or equal to 1:1.4 (H:V)
- Hydraulic jump may be completed within the culvert barrel

In situations where the runout section is too short and/or there is insufficient tailwater for a jump to be completed (or initiated) within the barrel, an outlet weir or a drop of the outlet followed by an outlet weir shall be designed. Sills are effective in forcing the hydraulic jump in broken-back culverts and in spreading the water back to the natural stream width.

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D. External Dissipators

External dissipators shall be designed where the outlet scour hole is not acceptable, moderate amount of debris is present, and the culvert outlet velocity is moderate, Fr < 3. Various types of external dissipators are discussed in the following sections.

Impact basin U.S. Bureau of Reclamation Type VI – The USBR Type VI basin was developed by the USBR and is contained in a relatively small box-like structure, with a vertical baffle. An opening is provided between the bottom of the baffle and the floor of the box.

The use of impact basin USBR Type VI is not recommended where debris or ice buildup may cause substantial clogging. The design of impact basin USBR Type VI shall achieve the guidelines presented below:

- Valid for discharges up to 400 cubic feet per second and velocities as high as 50 feet per second.
- In situations where the culvert entering the basin has a slope greater than 27 percent, the basin shall be constructed on a horizontal grade.
- The culvert shall provide a horizontal section at least four culvert widths in length immediately upstream of the dissipator.
- The end of the basin shall be provided with a low sill which, where feasible, shall be set at the same elevation as the downstream channel.
- Where needed to retain the roadway embankment, the end of the basin may be provided with an alternate end sill and 45 degree wingwalls.
- Where the velocities of flows exiting the basin exceed 5 feet per second, the channel downstream of the basin shall be provided with a riprap apron, per the guidelines presented in the Section on ‘Riprap Aprons’.
- A moderate depth of tailwater will improve its performance. However, the tailwater depth shall not be above half of the height of the baffle.

Hook type impact basin energy dissipator – The hook energy dissipator is a type of impact basin that abates culvert outflow velocities by means of three hook-shaped blocks and an end sill in a uniform trapezoidal channel or a warped wingwall basin. The minimum criteria for hook type basins are presented below:

- Hook type Basin with Uniform Trapezoidal Channel
  - The side slopes of the basin shall be between 1.5:1 (H:V) and 2:1 (H:V), and the bottom width of the basin shall be 1 to 2 times the effective opening width of the culvert.
  - Where scour may occur, a riprap apron shall be provided downstream of the basin, per the guidelines presented in the Section on ‘Riprap Aprons’.
  - A cutoff wall shall be provided at the end of the basin.

  - These basins may be used where the Froude number of the culvert outflow is between 1.8 and 3.0.

- Hook type Basin with warped wingwalls
  - Wingwalls warped from vertical at the culvert outlet to side slopes of 1.5:1 (H:V) at the end sill are recommended.
  - The recommended ratio of hook width/culvert width is 0.16.
  - The spacing between hooks shall be within the range of 1.5 to 2.5 times the hook width.
  - The height of wingwalls shall be at least twice the flow depth at the culvert exit.
  - A flare angle of 5.7 degrees per side is the optimum value for Fr > 2.45.
  - Where scour may occur, a riprap apron shall be provided downstream of the basin, per the guidelines presented in this Section on 'Riprap Aprons'.

Riprap aprons – Riprap aprons for culverts shall be designed in accordance with outlet protection criteria mentioned in the Section 8.5.3.4 of this chapter.

Riprap aprons for energy dissipators shall be designed per the equation:

$$D_{50} = 0.\frac{692}{(S-1)}\left(\frac{V^2}{2g}\right)$$

Where:

D_{50} = median rock size (feet)

S = rock specific gravity (pound per cubic foot)

V= velocity at the end of energy dissipator (feet per second)

E. <u>Stilling Basins</u>

Stilling basins shall be used where the outlet scour hole is not acceptable, debris is present, and the culvert outlet velocity (V_o) is high, Fr > 3.

Riprap basin – The riprap basin shall be considered where the standard riprap apron or other energy dissipators are inadequate. A riprap basin is a depressed area of riprap placed at the outlet of a high velocity culvert, storm drain outlet, or open channel. Recommended minimum criteria for riprap basin are as follows:

- The basin shall be pre-shaped and lined with riprap that is at least 2 x D_{50} thick.
- The ratio of depth of scour (ds) to rock size (D_{50}) shall be greater than 2.
- The length of the energy dissipating pool shall be 10 x (ds), and the length of the apron 5 x (ds).

- A riprap cutoff wall or sloping apron shall be constructed if downstream channel degradation is anticipated.

Saint Anthony Falls stilling basin – The Saint Anthony Falls stilling basin uses a forced hydraulic jump to dissipate energy. The design consists of a sloping chute with chute blocks at its base, followed by blocks on the floor of the basin. The basin floor also has a sill located at the downstream end. The basin sidewalls may be parallel for a rectangular stilling basin or may diverge, beginning at the downstream toe of the chute to create a flared stilling basin. A cut-off wall and wingwalls shall be provided at the end of the stilling basin. Minimum design criteria for Saint Anthony Falls stilling basin are provided below:

- Recommended where Fr = 1.7 to 17
- Requires a sufficient tailwater for efficient operation
- Sidewall flare shall not be greater than 0.5:1, 0.33:1, or flatter.
- Height of the baffles is set equal to the entering flow depth.
- Wingwalls shall be equal in height and length to the stilling basin sidewalls. Top of the wingwall shall have a 1:1 (H:V) slope.

8.5.2.5 Siphons

Inverted siphons (sometimes called sag culverts or sag lines), although not desirable, may be used to convey water by gravity under roads, railroads, other structures, various types of drainage channels and depressions. An inverted siphon structure shall operate without excess head when flowing at design capacity and shall not be used for drainage or irrigation where freezing may block the siphon's waterway.

Inverted siphons shall be used as follows:

- To carry flow under obstructions such as sanitary sewers, water mains, or any other structure or utility that may be in the path of the storm drain line.
- Where avoidance or adjustment of the utility is not practical

This section presents the minimal criteria and design standards for the hydraulic evaluation and design of inverted siphons. For criteria not included in this section, references shall be used as follows:

- Caltrans HDM design criteria shall be followed for design of siphons or sag culverts within roadways or highways.

A. <u>Pipe Material and Size</u>

Several pipe materials may be used for siphon construction:

- Welded smooth steel pipe with internal ceramic coating

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- Precast reinforced concrete pressure pipe
- Reinforced plastic mortar pressure pipe

The conduit size through the inverted siphon used as a storm drain system shall be the same size as either the approaching or exiting conduit. In no case shall the conduit size be smaller than the smallest of the approaching or exiting conduit.

B. Transitions, Head Losses, Cover and Slope

Transitions are defined as the inlet and outlet portion of an inverted siphon and shall be used to reduce head losses and prevent channel erosion in unlined channels. Siphon transitions shall be located outside the Authoirty's right-of-way. Concrete inlet and outlet transitions shall be used for:

- Siphons crossing tracks and paved highways
- 36-inch diameter and larger siphons crossing narrow (< 30 feet), unpaved, off-system roads
- Siphons in unlined channels with water velocities in excess of 3.5 feet per second in the siphon

Because an inverted siphon includes slopes of zero and adverse values, head losses through the structure due to friction, bends, junctions, and transitions shall be accounted. Sound engineering judgment shall be used to determine the maximum limits of head losses and if determined unacceptable, an alternative for the siphon design shall be considered. The total computed head loss shall be increased by 10 percent as a safety factor to ensure the siphon causing unexpected backwater.

The siphon profiles shall satisfy requirements of cover, siphon slopes, bend angles, and submergence of inlet and outlet.

- At siphons crossing tracks and roadways or highways, the minimum cover shall be based on the structural requirements of the siphon material.
- At siphons crossing under natural drainage channels, a minimum of 3 feet of compacted earth cover shall be provided.
- At siphons crossing under an earth channel, a minimum of 3 feet of compacted earth cover shall be provided.
- At siphons crossing under a lined channel, a minimum of 3 feet of compacted earth cover shall be provided between the bottom of the channel lining and the top of the siphon.

Siphon slopes shall not be steeper than 2:1 (H:V) and shall not be flatter than a slope of 0.005 feet/feet.

C. Velocity

The following velocity criteria are to be used in determining the length of the siphon:

- 3.5 feet per second or less for a short siphon not located under a trackway or highway with only earth transitions provided at entrance and exit,
- 2.5 feet per second or less for a short siphon located under tracks or highways with either a concrete transition or control structure provided at both inlet and outlet, and
- 10 feet per second or less for a long > 200-foot siphon with either a concrete transition or control structure provided at the inlet and a concrete transition provided at the outlet.

D. Collars and Blowoff Structures

Collars are placed at intervals along the siphon to reduce the velocity of any water moving along the outside of the siphon or through the surrounding earth thereby preventing removal of soil particles (piping) at the point of emergence. Siphon collars shall not be used, unless piping computations or observations of burrowing animals indicate they are needed.

Blowoff structures are provided at or near the low point of inverted siphons to permit draining the siphon for inspection and maintenance or shutdown. Siphons greater than 18 inches in diameter shall be equipped with a blowoff structure. An access hole or similar access shall be included with a blowoff on long siphons 36 inches and larger in diameter to provide an access point for inspection and maintenance. To facilitate removal of any accumulated sediments and to expedite the draining process, an 8-inch minimum gate valve shall be used. The drain pipe shall outfall where drain water will not cause any damage.

E. Freeboard

Upstream channel freeboard is commonly provided to accommodate intercepted storm runoff, improper operation or drift blockage. Freeboard criteria for siphons are listed as follows:

- The channel bank freeboard upstream from siphons shall be increased 50 percent or 1.0 foot maximum to prevent washouts at these locations.
- The increased freeboard shall extend upstream a distance from the structure such that damage caused by overtopping the channel banks would be minimal.
- If the freeboard shall extend upstream from the transition inlet, a minimum distance as determined by dividing the freeboard height by the channel slope shall be used. And, for freeboard downstream from the outlet transition, a minimum distance of 50 feet or to the Authority's right-of-way, whichever is less, shall be used.

F. Wasteways

Wasteways are often placed upstream from a siphon transition to divert the channel flow in case of an emergency. A wasteway, either separate or integral with the inlet transition, shall be provided where significant damage would occur due to escaping channel waters. Escaping waters shall be conveyed to a point and released in a manner to avoid trackway, roadway or property damage. Wasteways are not permitted within the Authority's right-of-way.

G. Safety Devices

Safety measures (e.g., fences, grates) shall be provided near siphons to protect persons and animals from injury and loss of life. A hazard can occur both when the siphon is operational or dry. Inlet and outlet transitions shall be hydraulically efficient and have removable grates to minimize the hazard associated with human or animal ingress or debris blockage.

8.5.2.6 Pump Stations

The use of pump stations at sag or sump points shall be avoided, when practical. Long-term operation and maintenance costs shall be identified and considered prior to implementation of pumps. The use of a gravity system shall be fully evaluated through the use of long pipelines or adjustments to the grade or track profiles, before pumps can be considered for the project. Where a gravity system cannot be provided and pump stations are unavoidable, pump station design within the corridor shall conform to the following:

- FHWA, Hydraulic Engineering Center (HEC)-24 on Highway Stormwater Pump Station Design
- *Mechanical* and *Facility Power and Lighting Systems* chapters of this Design Criteria

For pump stations installed for the project, but owned, operated and maintained by local agencies or a third party, the criteria to use shall be in accordance with the local governing agency.

Pump stations shall be designed to accommodate the inflow from a storm event according to Section 8.4.3. All possible flow shall bypass or pass-through downstream of the pump station, to reduce pumping requirements. Hydrological analyses of the watersheds that may discharge to the pump stations shall be carefully evaluated to avoid potential off-site drainage diversions from adjacent watersheds. The pump station design shall also address future build-out of the tributary watershed to verify that the pump station can handle increases in flow.

Pump Stations shall be designed to accommodate space for equipment cabinets and conduit and cabling to provide for SCADA control.

8.5.3 Culvert Hydraulics

Existing drainage facilities within the corridor shall not be negatively impacted due to the proposed design. Where a transverse undercrossing is required to convey surface runoff, flood waters, and/or existing streams across the Authority’s right-of-way, the crossing shall be provided within a culvert. When runoff is increased, existing culverts shall be upsized to allow for increase in flow.

The following sections outline minimal culvert criteria. For criteria not addressed in this section, references shall be used as follows:

- AREMA shall be followed for design of culverts along the corridor.

- Caltrans HDM shall be followed for design of culverts along roadways and highways impacted by the improvements.
- Local criteria shall be followed if AREMA and Caltrans criteria do not specify.

8.5.3.1 Design Elements

Numerous cross-sectional shapes are available to be used as culverts. The shape selection shall be based on the cost of construction, the limitation on the upstream water surface elevation, track and roadway embankment, available cover, and hydraulic performance.

The following culvert criteria shall be applied:

- Minimum culvert diameter/rise for trunk drains and culverts crossing under the track shall be 36 inches.
- Minimum culvert diameter/rise for lateral drains shall be 18 inches.
- Culverts and drains under platforms and station areas shall be a minimum of 18 inches.
- Culverts crossing under trackway shall be a minimum of 6 feet below top of rail and 3 feet below the flow line of ditch along the trackway.
- Culverts, within 45 feet of track centerline, shall have a minimum cover of 4 feet; culverts elsewhere shall have a minimum cover of 3 feet.
- In locations where the above criteria are not practical, reduced clearance may be provided with approval of the governing agency.

The selection of a culvert material shall consider structural strength, hydraulic performance and roughness, durability, corrosion and abrasion resistance. Common culvert materials are concrete, corrugated aluminum and corrugated steel. Culverts and storm drains passing beneath tracks or maintenance roadways shall be reinforced concrete pipe (RCP). Culverts and drains under platforms or in station areas that are not under tracks shall be RCP, polyvinyl chloride (PVC), high-density polyethylene (HDPE), or corrugated steel.

8.5.3.2 Location, Skew, and Slope

Culverts shall be placed to allow for cross-passage of surface runoff, flood waters, and where existing streams may exist. This may reduce embankment erosion, minimize debris buildup and, if placed often enough, limit carryover of drainage from one watershed to another. Culverts shall be in alignment and on the same gradient with existing streambeds. Curvatures in the alignment of the culvert and angle points shall be avoided.

The slope of the culvert shall be the same gradient of the existing streambed unless the topography is generally flat, in which case the invert of the inlet and outlet structures shall be designed to avoid sedimentation in the culvert. A minimum self cleaning velocity of 2.5 feet per second shall be used for culvert design.

8.5.3.3 Inlet Structure

For inlet control, a maximum allowable headwater of 1.5 times the culvert diameter/rise shall be used: For the 100-year storm event, a minimum freeboard between the water surface elevation and the subballast shall be 2 feet.

Upstream properties shall be protected from ponding and backwater effects from an undersized culvert. Ponding at the inlet structure shall be prevented. A larger culvert size shall be implemented if ponding and discharge backup are anticipated at the culvert entrance. Overtopping of the tracks is not permitted.

Sound engineering judgment shall be applied to inlet structure design.

A. Headwalls

Headwalls shall be used in locations where right-of-way is constrained, in areas where vegetation growth on slopes is limited, to improve the culverts appearance and increase the hydraulic efficiency. The headwall shall be designed to have adequate strength and proportion to prevent sliding or overturning from excessive soil pressures and to prevent settlement.

B. Wingwalls

Wingwalls shall be considered to prevent erosion and scour and provide soil stability around the proposed culvert. Perpendicular, oblique, or parallel wingwalls, or a combination thereof, shall be used, depending on the physical and hydraulic conditions involved. Wingwalls shall be carefully designed not to alter the historical flow patterns of the existing stream and prevent turbulence during peak storm events. An entrance apron and cutoff wall shall also be considered to prevent erosion and scour and increase hydraulic efficiency at the inlet.

C. Flared End Sections

Flared end sections improve hydraulic performance of the culvert by allowing a smooth transition between the natural channel and culvert and are aesthetically appealing. Due to these reasons, flared end sections are preferred to headwalls and wingwalls within the corridor.

8.5.3.4 Outlet Structure

Due to the unnatural constriction and material of culverts, the outlet velocity is generally higher than natural stream velocities. Energy dissipators or outlet embankment protection, such as slope paving, riprap, headwalls and wingwalls, end sections, cutoff walls and toe walls, shall be provided at culverts along the corridor to minimize downstream erosion and reduce drainage velocities. Natural flow patterns of the existing stream shall be restored downstream of the culvert, with special consideration of the channel transition for the 100-year flood.

Refer to Section 8.5.2.4 for design of energy dissipators.

8.6 Trackway and Facility Drainage Systems

8.6.1 Track Drainage Systems

Standing water along rail tracks may shunt the signal circuits causing signal failures. Hence, standing water along rail tracks is not permitted and shall drain away from the tracks. Track drainage shall be provided to drain storm water from tracks including cable troughs and right-of-way. Drainage criteria for cable troughs are provided in the *Civil* chapter. Underdrain track drainage pipe systems shall be used where right-of-way constraints make the standard flat bottom ditch or V-ditch unfeasible. Track drainage systems shall be used as a longitudinal drainage system, to capture the onsite run-off generated from the trackway. The collected run-off may be conveyed to a local storm drain system, based on the hydraulic capacity or, conveyed to the nearest natural water body, after applying appropriate treatment measures as defined in the BMP section of this chapter. Refer to Standard and Directive Drawings for detailed track drainage configuration. Pipe size, material, slope, and access hole requirements for a closed track drainage system shall be consistent with the criteria in Section 8.5.2.3.

In a shared corridor, drainage shall be kept separate from the drainage system of the third party operator. If any upgrades to the third party's drainage system are anticipated, they shall be performed based on the third party's design requirements.

For criteria not included in this section, references shall be used as follows:

- AREMA shall be followed for design of new track drainage facilities.

8.6.2 Embankments and Cut Slopes

For embankments that support the HST trackway and for cut slopes, refer to the *Geotechnical* chapter for drainage and slope protection requirements.

8.6.3 Bridges/Aerial Structures

Design of HST bridges and aerial structures over waterways and associated drainage facilities shall be coordinated with local agencies or the U.S. Army Corps of Engineers. The two basic designs involved in this section are the HST aerial structures and HST structures over waterways (HST bridges).

This section presents the minimal criteria and design standards for the hydraulic evaluation and design associated with bridge drainage within the corridor. For criteria not included in this section, references shall be used as follows:

- AREMA's "Roadway and Ballast" chapter for detailed information on the magnitude and level of scour created at piers and abutments and countermeasures
- HDS-01, Hydraulics of Bridge Waterways, FHWA for bridge hydraulic analyses
- HEC-21, Design of Bridge Deck Drainage, FHWA for bridge deck drainage design

- HEC-09, Debris Control Structures Evaluations and Countermeasures, FHWA for mitigating debris impacts to bridge structures
- Refer to local agency manuals for local criteria within each jurisdiction.
- The *Structures* chapter shall be referenced to ensure coordination with structural design of bridges and aerial structures.

8.6.3.1 Freeboard Protection

For the hydraulic design of bridges and aerial structures, a minimum of 2 feet of freeboard above the design frequency water surface elevation shall be provided.

8.6.3.2 Erosion Control and Scour Protection

Protection measures shall be taken to protect bridges or aerial structures, piers, and embankments from erosion and scour. Measures include providing riprap and/or vegetation on the slopes and streambed and increasing the distance between embankments. Where applicable, energy dissipators may be provided in accordance with criteria provided in Section 8.5.2.4.

8.6.3.3 Pier Design and Location

For structures over waterways, the spacing and location of the structural piers can significantly affect the hydraulic characteristics of the existing waterways. In locations where pier columns and protection walls interfere with drainage, an alternative drainage facility shall be provided to collect and carry water to a drainage system.

Piers shall be located outside of drainage channels and natural washes, where possible, to minimize negative impacts associated with scour and erosion at the pier. Where piers are located within channels, a streamlined design at the pier nose shall be considered. This shall be obtained by providing circular or rounded shapes at the upstream and downstream faces of piers in order to reduce flow separation, aligning bents with the direction of flow and increasing the length of the bridge to decrease velocities.

Debris buildup may occur at piers which can reduce the hydraulic capacity of the channel, increase the local scour, and potentially cause the pier to fail. The design shall consider the type of debris that could impact the pier. Depending on the debris type, protective devices such as steel plates, debris deflectors, wingwalls, and upstream debris catchment structures shall be used.

8.6.3.4 Deck Drainage System

Storm water on a bridge or aerial structure surface can affect the water spread on the structure into the trackway, cause complications with maintenance, and negatively impact the aesthetics of the structure, by corrosion or debris. The deck drainage system includes the bridge or aerial structure deck, gutters, inlets, pipes, downspouts and end collectors, which are discussed in the following subsections.

A. Bridge/Aerial Structure Deck

A longitudinal drainage system shall be provided along the deck to minimize standing water on the bridge or aerial structure. Criteria for bridge or aerial structure deck design are as follows:

- For bridges and aerial structures with ballasted track, the minimum pipe size shall conform to Section 8.6.1.
- For bridges and aerial structures with non-ballasted track, a drainage trough shall be designed to convey the deck drainage.
- The cross slope of the bridge/aerial structure deck shall be 2%.
- Standing water on the bridge or aerial structure shall not be permitted.

B. Inlets and End Collectors

The bridge and aerial structure end collectors are drainage inlets that collect flow before it reaches the structure and prevent flow from leaving the bridge or aerial structure. End collectors are typically drop inlets which convey a higher capacity; slotted drains may be used. Storm water upstream of a bridge or aerial structure shall be fully collected prior to reaching the structure. To avoid flooding on the bridge or aerial structure and backup in the pipes, inlets and drains on the bridge or aerial structure shall account for a 50 percent clogging factor. Water accumulating on structure decks with ballasted tracks shall be drained by a semicircular or U-shaped channel formed in the concrete invert at each track centerline. Inlets shall be provided at intervals to collect the flow into the storm drainage system.

C. Pipes and Downspouts

The minimum longitudinal slope of drain pipes inside the box girder shall be 1 percent or generate a minimum velocity of 2 feet per second. Downspouts shall be considered in the aesthetics of the bridge or aerial structure. Pipes and downspouts located within the concrete of the structure provide more challenges for access and maintenance. Cleanouts shall be provided at convenient and accessible locations along the pipe. Cleanouts shall be located such that these can be reached from the ground for easy access for personnel, and at places where the pipes bend and debris build-up may occur. Cleanout locations shall be identified.

Outfalls from downspouts may discharge directly into storm drains, or nearby receiving water, considering the water is treated before discharging offsite. If the downspout discharge is directly to surface drainage, the free-falling water shall not come into contact with the structure members to avoid corrosion and deterioration. Storm water from the bridge or aerial structure shall also not negatively impact the surface below; erosion control devices may be necessary at the outfall location and the surface channel shall be designed to carry and transfer the increase in flow. Downspouts that discharge directly to a storm drain shall connect to a manhole for easy access. The outfall invert shall be a minimum of 0.25 feet higher than the manhole invert to avoid debris clogging the storm drain.

8.6.4 Tunnels

For drainage requirements in tunnels, refer to Standard and Directive Drawings. Drainage from tunnel and cut-and-cover structures shall discharge to portals or to a low-point sump in pump station.

8.6.5 Retaining Walls

Provide a ditch behind retaining walls to redirect storm runoff away from the walls. For other drainage requirements at retaining walls, refer to the *Geotechnical* chapter.

8.6.6 Trenches

Where ground water table is high and interferes with the stability of track bed and side slopes, the trackway shall be in a trench section. Trench drainage discharges to a low-point sump in pump station and is discharged to local drainage system. Refer to the *Structures* chapter for trench wall heights for flood protection. For drainage requirements in trench sections, refer to Standard and Directive Drawings.

8.6.7 Critical HST Structures/Facilities

HST critical facility sites, such as Traction Electrification System, Automatic Train Control, vent structures, Traction Power Supply Sites, and yards shall be designed to drain so that the Finish Floor Elevation or top of slab foundation of the facility sites remain 6 inches above a 500-year flood elevation or 2 feet above 100-year flood elevation, whichever is greater.

8.6.8 Stations and Platforms

Positive drainage away from the walkways and platforms shall be provided. Outboard platform surfaces shall slope away from the trackbed for drainage of runoff from rainfall. Center platforms shall drain to the center of the platform with area drains for discharge to the nearest municipal drainage collection system. Refer to the *Stations* chapter for platform drainage requirements. Refer to Standard and Directive Drawings for station trackway drainage system within the station area.

Station drainage shall accommodate deluge system for depressed and underground stations.

8.6.9 Roadways

The following sections outline minimal drainage criteria for roadways, street improvements, parking lots and storm drains. For criteria not addressed in this section, references shall be used as follows:

- Caltrans HDM criteria shall be followed for design of roadway drainage, including subsurface drainage facilities within the corridor.
- For third party roadway drainage, refer to third party's drainage criteria.

8.6.9.1 Surface Drainage

Physical characteristics of roadways and highways, such as number of lanes, width of shoulder, longitudinal and cross slopes of the existing or proposed pavements, will affect the drainage design for streets. Water spread, velocity, and depth of water on the pavement shall be evaluated based on roadway geometry. The following design criteria shall be applied:

- Sheet flow on the roadway or highway shall be minimized to prevent hydroplaning.
- Cross flow shall not be more than 0.1 cubic feet per second.
- Ponding shall be prevented in station parking lots where vehicle stalls are located.
- Sound engineering judgment shall be used with careful consideration to train, vehicular and pedestrian traffic.

8.6.9.2 Storm Drain Design

Storm drains shall be designed in coordination with roadway and trackway surface flow. Inlets, subsurface piping, and maintenance access shall be considered when designing storm drains. Refer to the *Utilities* chapter for clearance requirements of storm drain facilities with adjacent infrastructure facilities.

8.6.9.3 Inlets and Maintenance Access

Inlet types may include curb-opening inlets, grate inlets, slotted drain inlets and a combination of all these types. Inlet type shall consider the proposed location of the inlet, whether highways or local roadways, and the required capture capacity the inlet must convey. The location and spacing of inlets shall be designed such as to prevent ponding and flooding in traveled lanes. Inlets are generally placed upstream of pedestrian ramps and street intersections. Grate inlets are not recommended for pedestrian pathways. Inlets shall be placed prior to a superelevation reversal to prevent cross flow on the roadway.

Inlet capacity depends on the size and shape of the opening, grate type and the roadway geometry upstream of the inlet. To mitigate back-up and ponding of water, a minimum clogging factor of 50 percent shall be used for all inlet designs.

Design of manholes shall conform to the following maintenance hole spacing requirements:

Table 8-5: Maximum Manhole Spacing Requirements

Pipe Diameter	Maximum Spacing Requirements
Any pipe that cannot reach a self-cleaning velocity of 2.5 ft/s	300 feet
Less than 24-inches	400 feet
24 inches to 48 inches	400 feet to 800 feet
Greater than 48 inches	1,200 feet

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Engineering judgment shall be used in determining spacing requirements. Access logistics for pipe maintenance shall be considered. Manholes and associated storm drains shall be located out of the highway traveled way and intersections to avoid disruptions to traffic. If the subsurface drain is proposed to cross the tracks, manholes shall be considered at the Authority's right-of-way limits.

8.6.9.4 Pipe Characteristics

Subsurface pipes shall be designed at full flow capacity. To determine the appropriate pipe size, shape and material, Manning's equation shall be applied as described in Section 8.5.2. Storm drains may operate under pressure, provided the pipe material will not be jeopardized due to pressurization; however, the hydraulic grade line shall not rise above the manhole or inlet structure, and shall be a minimum of 1 foot below the surface finished grade.

Generally in urban areas, storm drain pipes are RCP material to provide a longer life of the system and minimize maintenance over the life of the pipe. RCP pipes shall be designed for facilities crossing under the tracks. Other pipe materials, including corrugated steel, HDPE and PVC may be considered along the corridor and at train stations, provided that there is minimal maintenance over the life of the pipe. Criteria for pipe size and cover are presented as follows:

- Minimum pipe size under tracks shall be 36 inches or equivalent.
- Minimum pipe size at station facilities and roadways shall be 18 inches.
- Minimum cover of 6 feet from top of pipe to top of rail for pipes crossing beneath tracks and 4-foot minimum for pipes at all other locations.
- A 3-foot minimum cover shall be provided for pipes under the flowline of the ditch next to the track.

8.7 Detention/Retention of Surface Water Runoff

The main purpose of a detention basin is to temporarily store runoff volume to reduce peak discharge by allowing flow to be discharged at a controlled rate. This section provides minimal design criteria for hydraulic evaluation and design of detention basins, for the purpose of flood control and storm water management.

Caltrans identifies detention basins as a design pollution prevention BMP, which temporarily detains runoff to allow sediment and pollutant to settle. If the detention basins are designed to include the purpose of a BMP, reference shall be made to Section 8.8. Proper treatment of polluted runoff shall be included in the design of the detention/retention basins. Retention storage can be defined as a depression or low point where water accumulates with no possibility for escape as runoff. These facilities allow for infiltration into underlying soils, and are considered as "Infiltration Devices."

Several factors such as the peak outflows, spillway sizing, and sedimentation govern the design of detention facilities. For design criteria and detailed design methodologies of detention basins not included in this section, refer to HEC-22, Urban Drainage Design Manual, FHWA.

8.7.1 Peak Flow Reduction and Release Rate

The facility's outlet structure shall limit the maximum outflow to allowable release rates. The maximum release rate may be a function of existing or developed runoff rates, downstream channel capacity, potential flooding conditions, and/or local agency regulations.

The system shall be designed to release excess storm water expeditiously to ensure that the entire storage volume is available for subsequent storms. The facilities may need a paved low flow channel to ensure complete removal of water and to aid in nuisance control.

8.7.2 Required Storage Estimate

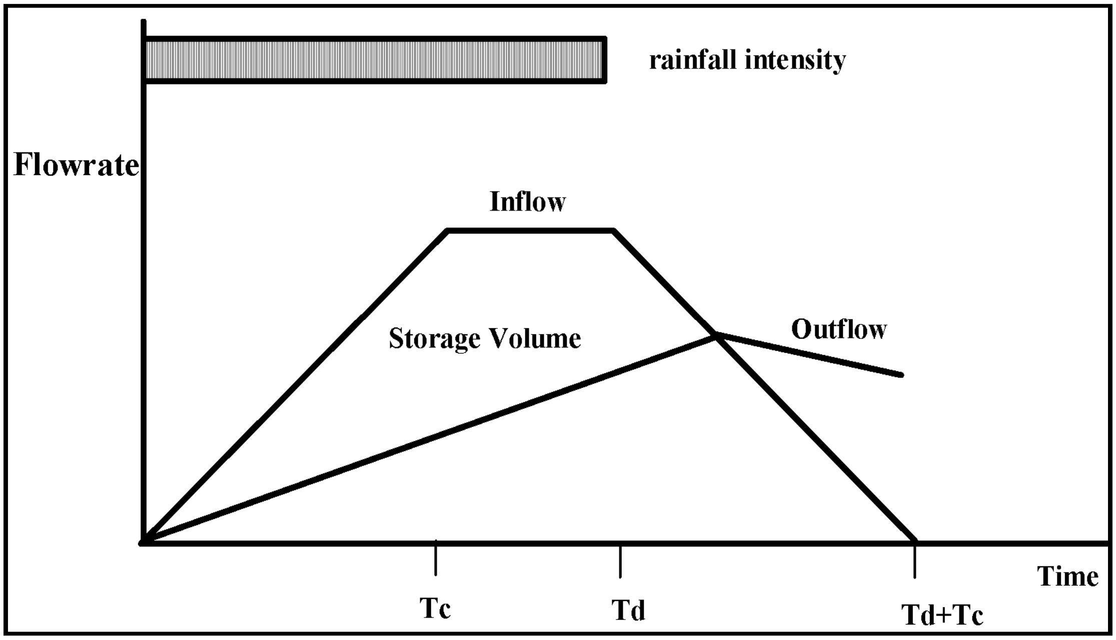
For watersheds greater than 150 acres, the required volume of storage for a detention basin that is necessary for peak flow reduction can be estimated as the difference between the inflow and the outflow hydrographs, using the Hydrograph Method.

The Volumetric Method shall be used to estimate the runoff detention/retention volume for watersheds less than 150 acres for the urban catchment. In this case, uniform rainfall is assumed and the required storage volume can be estimated by the volume difference between the rainfall volume coming to the basin and the runoff volume released from the basin. For simplicity, trapezoidal hydrograph shown on Figure 8-1 can be considered for volume calculation. The inflow hydrograph has a linear rising limb over the time of concentration of the tributary watershed and the peaking portion of the inflow hydrograph is a plateau from the time of concentration, to the end of rainfall event. The effective rainfall volume is represented by the storage volume shown in the graph, where:

T_c = Time of Concentration (minutes)

T_d = Rainfall Duration (minutes)

Figure 8-1: Trapezoidal Hydrograph



Source: "Detention Basin Sizing for Small Urban Catchments", ASCE J. of Water Resources Planning and Management, Vol. 125, No. 6, November.

8.7.3 Basin Sizing

A stage-storage relationship defines the relationship between the depth of water and storage volume in a detention basin facility. The basin width to length ratio shall be greater than two so that the flood flows can sufficiently expand and diffuse into the water body to enhance the sedimentation process. Slopes on embankments have to maintain the bank slope stability. Slopes on earthen embankments shall not be steeper than 4:1 (H:V) and on riprap embankments shall not be steeper than 3:1 (H:V).

Detention basins may be designed in rectangular, triangular, trapezoidal or elliptical shapes, depending on the available right-of-way and required volume of storage. Once the storage volume is determined, the storage basin configuration is determined by multiple layers to accommodate the 10-, 25-, and 100-year storm event storage volumes.

8.7.4 Outlet Structures and Emergency Spillways

Outlet structures of a detention basin consist of low flow outlets and emergency spillway. The outlet structure is formed by risers, perforated plates, orifices, weirs, and culverts. The minimum size of a low flow outlet shall be 18 inches. The low flow outlets are designed based on the orifice principle, while the emergency spillway is designed based on weir equations. The invert of the emergency spillway shall be 2 feet above the major design storm water surface elevation. It is recommended to have a minimum of 1 foot freeboard.

The obstruction to low flow conduits by debris can reduce outlet design release rate and cause the premature filling of the detention basin with storm water, reducing the flood protection provided by the structure. All outlet works and low flow conduits shall be provided with a trash rack for debris control. The trash rack shall provide a maximum bar spacing not to exceed two-thirds of the outlet opening or diameter. The total area of the trash rack shall allow for passage of the design flow with 50 percent of the trash rack blocked.

8.8 Storm Water Quality Management

The United States Environmental Protection Agency has designated the State Water Resources Control Board to monitor the state-wide storm water management program within the State of California. The State Water Resources Control Board issued a National Pollutant Discharge Elimination System permit that regulates storm water discharges from facilities. Further, local governing agencies such as Regional Water Quality Control Boards (RWQCBs) may consider additional requirements to meet water quality standards. In particular, where a local storm drainage system is not available, such as in rural farm land areas, water treatment requirements shall follow the environmental permits issued by the appropriate regulatory agencies.

An effective storm water management program involves incorporating storm water BMPs during the planning and design phases (permanent BMPs), as well as during the construction phases (temporary BMPs) of a project. The designer shall identify the pollutants of concern in the storm water discharge because they can have numerous negative impacts such as the following:

- Reducing the storage capacity of hydraulic facilities due to the deposition of sediment and silt
- Increasing toxic release to aquatic life due to the metal dust and toxic fluids from train/vehicle leaks
- Contributing to non biodegradable pollutants such as street litter

Two major types of permanent BMPs are design pollution prevention BMPs and treatment BMPs. The Caltrans Storm Water Data Report (SWDR) is a project specific document that shall be prepared for each phase of the project and usually documents the permanent BMPs. The most common temporary BMPs are the construction site BMPs, usually documented using a Storm Water Pollution Prevention Plan (SWPPP). For guidance on evaluation, selection, and design criteria on permanent BMPs, SWDR, temporary BMPs, and SWPPP, references shall be used as follows:

- The Caltrans Storm Water Quality Handbooks, Project Planning and Design Guide, for design of BMPs.
- The Caltrans HDM design criteria shall be followed for design of storm water BMPs within roadways or highways.

- The Caltrans Storm Water Quality Handbooks, Construction Site Best Management Practices manual for implementation of storm water BMPs during construction.
- The RWQCB shall be contacted and/or referenced for guidance, where necessary.

8.9 Application of Approved Software

The use of industry accepted hydrologic/hydraulic design programs is recommended. Where the drainage facilities impact or connect to facilities owned by others, local agency criteria shall be applied. The Caltrans HDM General Aspects chapter may be referred for approved software in use.

Chapter 9

Utilities

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Revision	Date	Description
0	02 Mar 12	Initial Release, R0
0.1	Dec 2012	EXECUTION VERSION

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Acronyms

Authority	California High-Speed Rail Authority
AREMA	American Railway Engineering and Maintenance-of-Way Association
Caltrans	California Department of Transportation
CFR	Code of Federal Regulations
CHST	California High-Speed Train
CPUC	California Public Utilities Commission
GO	General Order
HV	High Voltage
NFPA	National Fire Protection Association
OCS	Overhead Contact System

9 Utilities

9.1 Scope

This chapter provides guidance on standards and procedures for the location, assessment, protection, relocation and placement of underground and overhead utilities located within and in proximity to the California High-Speed Rail Authority's (Authority's) right-of-way (shared or exclusive).

The approach for assessing and addressing third party (non-CHST) utility impacts is broadly based on the desire to limit the number of transverse encroachments, eliminate longitudinal encroachments, and eliminate the need for maintenance of non-CHST utilities within the Authority's right-of-way. Utilities specified herein shall include: all physical services, such as electrical power, gas, water, telephone, cable TV, fiber optics, sanitary sewers, other public and private utilities and supporting facilities required to be placed or relocated in the Authority's right-of-way. This chapter does not address California High-Speed Train (CHST) storm drains and irrigation systems. Guidance for design and identification of these utilities and supporting facilities will be included in separate chapters of this Design Criteria.

9.2 Regulations, Codes, Standards, and Guidelines

Refer to the *General* chapter for requirements pertaining to regulations, codes, and standards. In addition to the laws and standards relevant to any facility, standards specific to railroad facilities shall be applied.

- Code of Federal Regulations (CFR), Title 49
- California Government Codes
- California Public Utilities Commission (CPUC) General Orders (GOs), Public Utility Codes, Rules of Practice and Procedure, and the Policies and Guidelines
- National Fire Protection Association (NFPA) Standards
- California Department of Transportation (Caltrans)
    - Caltrans Highway Design Manual (HDM)
    - Caltrans Project Development Procedures Manual (PDPM)
- American Railway Engineering and Maintenance-of-Way Association (AREMA) Manual for Railway Engineering

For installation of utilities, applicable local building, planning and zoning codes and laws shall be reviewed for the passenger stations, maintenance or service facilities as they may be located within multiple municipal jurisdictions or state right-of-way.

9.3 Policies and Agreements

9.3.1 Policies

- Protect the Authority's facilities and right-of-way against damage caused by presence of a utility.
- To the extent that is reasonable and feasible, exclude access points for utilities from within access controlled right-of-way. This policy is intended to provide a safe environment for operations, minimize inconvenience to the traveling public, and eliminate conditions detrimental to the safety of utility employees during maintenance of its facilities.
- Provide a means of inspection, maintenance, and repair of utilities, as may be required, without disruption of train service.
- Satisfy requirements and criteria of the affected utility owners, however, no betterment shall be included unless specifically agreed between the utility owner and the Authority.

9.3.2 Agreements

- The Designer shall coordinate with the Authority and utility owner as needed for the rearrangement of the utilities within and adjacent to the Authority's right-of-way.
- Technical requirements of pertinent utility agreement shall be incorporated into the design.
- The Designer shall be responsible for coordinating plans developed or being developed by others in adjoining areas to ensure that the overall utility systems will be comparable to those existing before start of construction and that they will be compatible with project operations.
- New construction and the protection, support, restoration, and rearrangement of utilities shall be in conformance with the latest technical specifications and practices of the respective utility owner.
- Non-CHST utility design performed by the Designer requires approval by utility owner in coordination with the Authority.
- In the event that there are no standards, design shall be in accordance with these Design Criteria and the current design criteria and engineering practices for the particular utility involved.

9.4 CHST Utilities

CHST utilities are defined as utilities and supporting facilities that serve CHST Systems' facilities.

9.4.1 Electrical

- Electrical service utilities and supporting facilities transmit electrical power from its traction power or facility power substations to facilities such as Overhead Contact System (OCS), ventilation structures, train control houses, passenger stations, and other appurtenant wayside facilities.
- Various local or regional power companies provide power to traction power and facility power substations.
- If a power company's substation is located within the Authority's right-of-way, the design of the substation site shall follow the requirements of that power company, section 9.5.5.7 of this chapter on Aboveground Utility Facilities, the *Facility Power and Lighting Systems*, and the *Traction Power Supply System* chapters. In case of a conflict, the more stringent requirements shall be followed.
- Electrical distribution facilities shall be surface mounted on foundations, supported on structures, or installed underground. Refer to *Facility Power and Lighting Systems* chapter for design requirements.
- Unless otherwise specified, each utility power company will design, furnish, and install all of its cables and/or overhead conductors, including all high voltage (HV) utilities and supporting facilities and connection, from the utility's network up to the point of common coupling (interface connection point).
- Systems duct banks, manholes, and cables located within the Authority's right-of-way or from interface connection point shall be designed by the Designer.

9.4.1.1 Duct Banks

For design of underground duct banks, see the *Facility Power and Lighting Systems* chapter, *Communications* chapter, and Standard Specifications.

9.4.1.2 Manholes and Handholes

Standard manhole and handhole sizes shall be used whenever possible. Refer to the *Facility Power and Lighting Systems* chapter, *Communications* chapter, and Standard Specifications for more information.

9.4.1.3 Service Connections

Those portions of utility service connections to utilities and supporting facilities that lie outside of structures, such as traction power substations, train control houses, etc., shall be shown on the utilities plans. The Designer shall coordinate the service connections with other items of work. The Designer shall ensure that service connections are indicated on either its plans or those for the adjacent construction contracts.

9.4.2 Fuel Lines

- The design and installation of fuel lines (gas and petroleum) to facilities from service main up to the meter will be done by the individual utility companies providing the fuel, unless otherwise indicated in the agreement between the Authority and the utility company.
- The size of fuel supply line and the meter shall be based on peak-demand calculations provided by the Designer.
- The clearance requirements for the fuel pipe shall be per the requirements of the utility owner (up to the meter) and of this Design Criteria (from the meter to the facilities).
- The design and installation fuel lines within Authority's right-of-way shall comply with the requirements of NFPA 130 and local jurisdictional requirements. In case of a conflict, the more stringent requirement shall be applied.
- The meter for fuel lines shall be in public right-of-way or in a location accessible to the utility company.
- Corrosion control measures for fuel pipelines shall be applied in accordance with the following:
  - Federal Safety Standards for Gas Lines, Title 49 CFR, Part 192
  - Section 9.5.6.4 of this chapter on Cathodic Protection and Corrosion Control
  - The utility company standards and practice

9.4.3 Water

Fire and domestic (potable and non-potable) water service connections shall be designed by the Designer. The size of the domestic connection and meter shall be based upon a peak-demand pressure-loss calculation. The domestic service meter shall be located in public right-of-way or in a location accessible to the utility company and shall meet the requirements of the water company providing the water meter.

Fire flow and pressure data in the existing water main will be furnished by the municipal agency in consultation with the Fire Marshal having jurisdiction. The fire service in public right-of-way and domestic services up to the Authority's right-of-way and including the meter will be installed by the utility or Authority's contractor, as determined by the utility. Location of Fire Hydrants within the Authority's right-of-way shall be coordinated with and approved by the Fire Marshal having jurisdiction of the site. For standpipe design and installation within passenger station areas and CHST tunnels, refer to the *Fire Protection* chapter.

9.4.4 Sewer

Sewer services shall meet the requirements of the Sanitary Sewer District and the appropriate municipal building code. The Designer shall be responsible for sizing and establishing the slope of the sewer services, however, the minimum allowable diameter for a sanitary sewer shall be 8

inches with a minimum slope of 0.7 percent. Location of sanitary sewer manholes shall be accessible to maintenance staff.

9.4.5 Telephone/Communications

Conduits and wiring for public telephone in passenger stations and parking lots, from the telephone service points to each public telephone location, shall be designed by the Designer and installed by the Contractor. The location and elevation of the conduit stub at the property line shall be indicated on the plans. Unless otherwise specified in the agreement between the Authority and the telephone company, the design and installation of conduits and wirings from telephone distribution network to the Authority's right-of-way shall be performed by the telephone company and the portion within the Authority's right-of-way will be performed by the Designer. Public telephones will be installed by the telephone company. All telephone company conduits and cables shall be terminated at the Entrance Facility room at each passenger station, building, or facility as described in the *Communications* chapter. Also, refer to the *Stations* chapter for general location, quantity, and description of public phones in passenger station areas.

9.5 Non-CHST Utilities

Non-CHST utilities are defined as utilities and supporting facilities belonging to governmental agencies, public utility corporations, railroads, privately owned companies, and private parties for the provision of sewer, water, drainage, gas, electrical, steam, telephone, cable TV, petroleum product pipelines, fiber optics, and other communications systems. Non-CHST utilities are mainly transmission lines, distribution lines, and the service connections to adjacent properties that are not related to CHST operations.

All non-CHST utilities to be relocated, abandoned, or protected in place during construction, whether done by the Authority's Contractor or the utility owner, shall be addressed in the construction documents.

9.5.1 High Risk and Low Risk Utilities

Utilities conducting toxic or flammable gases or liquids, pressurized waterlines greater than 80 psi normal operating pressure or in pipelines greater than 8 inches in diameter, and underground electrical supply lines that have potential to ground more than 300 volts, which do not have concentric grounded or effectively grounded metal shields or sheaths, are considered High Risk utilities.

All other utilities are considered Low Risk utilities.

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9.5.2 Right-of-Way Encroachment

An encroachment is defined as any structure or object of any kind which is within the Authority's right-of-way but not part of the CHST facility. Encroachments allow temporary or permanent use of Authority's right-of-way by a utility, a public entity, or a private party. Encroachments include all public and private utilities within the Authority's right-of-way.

The Authority's policy is, to the extent that is reasonable and feasible, to exclude access points for utilities from within access controlled right-of-way. This policy is intended to provide a safe environment for operations, minimize inconvenience to the traveling public, and eliminate conditions detrimental to the safety of utility employees during maintenance of its utilities and supporting facilities.

High Risk utilities and supporting facilities shall not be allowed on Authority's aerial structures, tunnels or through any underground/subgrade trackway under any circumstances.

9.5.3 Encroachment Justifications

Access to non-CHST utilities from the Authority's right-of-way is an exception to criteria and requires Authority's approval.

Where longitudinal or transverse encroachments and installations are required, the Designer shall ensure the following:

- An alternate location is not feasible, from the standpoint of providing efficient utility services in a manner conducive to safety, durability, and economy of maintenance and operations.
- The accommodation will not adversely affect the design, construction, operation, maintenance, safety, or stability of CHST utilities and supporting facilities.
- The accommodation will not interfere with or impair the proposed use or future expansion of CHST utilities and supporting facilities.
- The disapproval of the use of the Authority's right-of-way would result in an immitigable impact to the owner, the environment, or the public.
- The utility will be located in such a manner that it can be serviced, maintained, and operated without being accessed from within the Authority's right-of-way and will not adversely affect safety or cause damage to CHST utilities and supporting facilities.

9.5.3.1 Longitudinal Encroachments

Existing Utility Longitudinal Encroachments – Longitudinal utility encroachments within the Authority's right-of-way shall be considered on a case-by-case basis.

Existing longitudinal utilities located within the existing or proposed Authority's right-of-way shall be relocated to the outside of the Authority's right-of-way unless it can be shown to meet the encroachment justification requirements noted above.

New Utility Longitudinal Encroachments – New non-CHST utilities will not be permitted to be installed longitudinally within access controlled areas. Deviation from this requirement requires Authority's approval.

9.5.3.2 Transverse Encroachments

New utility installations and adjustments or relocation of existing utilities may be permitted to cross the Authority's right-of-way.

To the extent feasible and practicable, they should cross on a line generally normal to, but not less than 60 degrees from the railroad longitudinal alignment.

Transverse crossings that are at less than 60 degrees from the railroad longitudinal alignment shall be classified as a longitudinal encroachment.

Transverse utility encroachments shall comply with the encroachment justification requirements noted above.

With the exception of HV transmission lines and the utilities that can be placed in roadway structures going over CHST utilities and supporting facilities, all utility transverse crossings shall be undergrounded. Refer to the *Overhead Contact System and Traction Power Return System* chapter for HV clearance requirements over CHST utilities and supporting facilities.

Air space leases for wireless communications facilities fall under the general guideline for transverse encroachments and are to be reviewed by and concurred with the Authority which may develop special guidelines for wireless communication facilities.

9.5.4 Rearrangement

To the extent that is reasonable and feasible, proposed non-CHST utilities shall be located outside the Authority's right-of-way. The location, design, and construction of relocated or proposed utilities shall meet the requirements of CPUC GOs and the provisions of this chapter.

In performing utilities rearrangements, due consideration shall be given to the needs of the CHST Systems' design, the requirements and obligations of the utility owners, and policies established by the Authority. If temporarily relocated, existing utilities shall be restored upon completion of work. If permanently relocated, the new utility shall be operational before or coincident with the termination of the existing service.

9.5.4.1 Identification of Existing Utilities

The Designer is responsible for determining the identification and location of all utility facilities that lie within the planned construction right-of-way boundaries. This is accomplished by the following:

- Review of procurement documents

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- Review of railroads, State, County, or other local jurisdiction's as-builts, permit records, and geographic information system
- A joint field review of the project area with the Authority or its designee (Utility Coordinator) and utility owner's representatives.

The need for utility identification and verification is twofold:

- To identify all potential/project conflicts so they may be cleared before project construction commences, either through avoidance or relocation
- To meet the requirements of California Government Code Section 4215

9.5.4.2 Utility Verification Request to Owner

The Designer, through the Authority, shall furnish verification maps to each utility owner detailing existing or potentially existing utilities and supporting facilities within the project area. The request letter shall include the elements shown in Caltrans Right-of-Way Manual Chapter 13 Exhibit 13-EX-10. The Designer shall request the utility owner to update the maps for all utilities and supporting facilities including any abandoned facility. Normally the utility owner is allowed 30 days to respond. The Designer shall be responsible for follow-up to ensure timely completion of verification. (See also CPUC GO No. 128, Rule 17.7 for legal requirements for regulated utility owner to provide facility location information.)

9.5.4.3 Positive Location of Underground Utilities

Positive location of all High Risk or Low Risk utilities and supporting facilities shall be accomplished by potholing or other acceptable methods as determined by the utility owner to determine horizontal and vertical position of the facility. Combination of methods may be more effective than a single method. The Designer, through the Authority, shall make a written request to the utility owner for the positive location of their utility facility. With the concurrence of the utility owner, potholing and surveying of the utility shall be performed by the Designer.

All utilities and supporting facilities within the construction area must be positively located within 0.5 feet for both horizontal and vertical location. For transverse utilities and supporting facilities, the positive location should be made on either side of the trackway and other critical locations. For longitudinal utilities and supporting facilities, the locations must be done at intervals sufficient to establish the location of the line but in no event at greater than 100-foot intervals. Machine excavation to expose the High Risk or Low Risk utilities and supporting facilities in order to physically locate them must be done by, or at the authorization of, the utility/facility owner.

9.5.4.4 Level of Service and Service Interruptions

A level of service equivalent to the existing service shall be maintained for adjacent properties, residents, and businesses throughout construction by supporting utilities in place, diverting utilities, or providing alternative temporary utilities and supporting facilities.

If necessary, interruption of existing utilities service shall be minimized. Service shall not be interrupted without the prior written consent of utility owners.

9.5.4.5 Placement

Pipes shall be designed to support dead loads imposed by earth, subbase, pavement, ballast, structures, track, and dynamic forces exerted by anticipated traffic loads when the pipe is operated with the design range of internal pressure from maximum to zero.

Utility lines crossing beneath at-grade trackway shall conform to Pipelines section of the AREMA Manual for Railway Engineering, except as modified in these criteria, and the following:

- Casing pipes shall be provided for all utility carrier pipes crossing trackway and structure foundations and buildings.
- Electrical ducts, telephone, and fiber optic conduits in ducts will not require casing pipe where the ducts are encased in concrete and the strength of the utility facility is capable of withstanding rail system loading. Refer to *Structures* chapter for system loading requirements.
- Where new trackways are constructed over existing utilities that are not in conflict with the construction and operations of the Systems' conduits and existing utilities to be continued in service, the utility facilities shall be uncovered and encased. The limit of casing is discussed below.
- Utilities shall not be placed in any manner or position which may cause damage to or impair the safety of the Systems' conduits.
- Utilities shall not be placed within culverts and/or under waterway crossings.
- Where a utility crosses a CHST utility within the Authority's right-of-way, the CHST utility shall be maintained above the third party utility.

When utility and supporting facility rearrangement will be designed by the facility owner, the Designer shall coordinate and furnish data so that the owner may complete its design in a timely fashion. The Designer shall review the facility owner's proposal to ensure that it is compatible with the Systems' conduit design and that of other affected owners. The Designer shall include such arrangement as facility alignments on its plans and shall provide appropriate copies for distribution to affected facility owners.

9.5.4.6 Carrier Pipes

For non-flammable substances, the carrier pipe and joints within the Authority's right-of-way shall be of acceptable material and construction per AREMA Standards. Joints for carrier pipe operating under pressure shall be mechanical or welded per AREMA and ASTM requirements. Resilient type joints shall be used where the combination of fill height and foundation soil compressibility could adversely affect the permanence and watertightness of rigid type joints.

For flammable substances, the carrier pipe that has to be relocated or replaced within the Authority's right-of-way shall be designed, installed, and tested in accordance with the current standards of the utility owner and the following:

- Title 49 CFR Part 192, "Transportation of Natural and Other Gas by Pipeline: Minimum Federal Safety Standards", and Part 195, "Transportation of Hazardous Liquids by Pipeline"
- ASME B31.8, "Gas Transmission and Distribution Piping Systems" and ASME B31.5, "Liquid Transportation System for Hydrocarbons, Liquid Petroleum Gas, Anhydrous Ammonia and Alcohols – ASME B31.4"
- "API Recommended Practice (PR 1102) for steel Pipeline Crossing Railroads and Highways."
- CPUC GO No. 112-D, " Rule Governing Design, Construction Testing, Maintenance and Operation of Utility Gas Gathering, Transmission and Distribution Piping System" except that allowable stresses for the design of steel pipe shall conform to the requirements of AREMA Standards
- Steel carrier pipes shall be protectively coated and provided with a cathodic protection system and test monitoring facilities in conformance with the *Corrosion Control* chapter.
- Pipelines carrying flammable gas products shall not, where practicable, cross any portion of the Systems' conduits where tracks are carried on an embankment.
- Liquid-petroleum lines in proximity or crossing underground structures shall also conform to the requirements of NFPA 130.

9.5.4.7 Casings

Underground utilities and supporting facilities located within the Authority's right-of-way, except for electrical and communication lines, shall be located in a steel casing pipe (3/8 inch minimum thickness) with welded joints.

- Casings shall consist of steel, corrugated steel, ductile iron, or reinforced concrete pipe in accordance with the latest industry codes and standards, AREMA Specifications, and the requirements specified below.
- Casing pipes and joints shall be watertight and shall be capable of withstanding train loading as specified in the *Structures* chapter.
- Casings shall be sloped to drain.
- Casings shall be protected against corrosion by using corrosion resistant casing material and interior and exterior protective coatings, or other approved methods in conformance with the requirements of this chapter and the *Corrosion Control* chapter. Care shall be taken to select materials which will not be damaged through contact with dissimilar metal.
- Cathodic protection may be required for casings, as required by the utility owners design criteria.

- Metallic casings shall be grounded and bonded in conformance with the requirements of the *Grounding and Bonding Requirements* chapter.
- Steel casing pipe shall have a minimum yield strength of 35,000 psi. Wall thickness for steel casing pipe shall conform to AREMA Specifications.
- Ductile iron pipe may be used for a casing provided the method of installation is by open trench. Ductile iron pipe shall conform to ANSI A21.51. The pipe shall be of the mechanical-joint type or plain-end pipe with compression-type couplings.
  - For non-flammable substances the strength of ductile iron pipe shall be computed in accordance with AWWA C150, Thickness Design of Ductile-Iron Pipe, to sustain external loads.
  - For flammable substances ductile iron pipe shall conform to AWWA C151, Ductile Iron Pipe, and Centrifugally Cast for Water and Other Liquids.
- Reinforced concrete pipe, with gasketed watertight joints, may be used for a casing pipe for non-pressurized utilities.
- The inside diameter of the casing pipe shall be sized to allow the carrier pipe to be removed subsequently without disturbing the casing pipe or trackway. All joints or couplings, supports, insulators, and centering devices for the carrier pipe within a casing shall be taken into account. In no case shall the casing pipe be sized smaller than the following:
  - The inside diameter of the casing pipe shall be at least 2 inches greater than the largest outside diameter of the carrier pipe, joints and couplings.
  - The minimum size of a casing pipe shall not be less than 24 inches.
- Casing pipe shall extend to the greater of the following distances, measured at the right angle to the centerline of the track:
  - A minimum distance of 1 foot outside the fenced portion of the Authority's operating right-of-way, or wherever practical a distance of 1 foot outside the Authority's right-of-way.
  - A minimum distance of 25 feet from the centerline of outside track when extending the casing beyond the Authority's fenced right-of-way is not practical and the end of casing is below ground.
- Where the ends of the casing are below ground, they shall be properly protected against the entrance of foreign material, but shall not be tightly sealed.
- Where the ends of the casing are at or above ground surface and above high-water level, they may be left open provided drainage is afforded in such a manner that leakage will be conducted away from the tracks or structures.
- CPUC GO No. 128, "Rule for Construction of Underground Electrical Supply and Communication Systems" shall govern for all pertinent applications.

- Casings carrying fluids and gases shall be properly vented. Vent pipes shall be of sufficient diameter, but in no case less than 2 inches in diameter, projecting through the ground surface beyond the Authority's right-of-way line. Vent pipes shall extend no less than 4 feet above the ground surface. Top of vent pipes shall be fitted with a down-turned elbow, properly screened.

9.5.5 Utility Clearances

The minimum requirements for utility clearances shall be as defined by the CPUC GOs as applicable, Caltrans HDM and PDPM, AREMA, utility owner's requirements, and these Design Criteria. The Designer shall use the most stringent and conservative clearance requirements as determined from these documents. These requirements apply to CHST Systems related facilities as well as those owned by others.

In addition, High Risk and Low Risk utilities shall comply with the following requirements:

- High Risk Utilities
  - Maintain 500 feet minimum horizontal separation from flammable gas or hazardous liquid utility to other High Risk utilities
  - Maintain 50 feet minimum horizontal separation from non-flammable gas or hazardous liquid utility to other High Risk utilities
  - Maintain 5 feet minimum horizontal separation from other Low Risk utilities
  - Maintain 20 feet minimum horizontal separation from non-load carrying and load carrying structural elements, including OCS pole foundations and downguys
- Low Risk Utilities
  - Maintain 3 feet minimum horizontal separation from other Low Risk utilities
  - Maintain 5 feet minimum horizontal separation from load carrying structural elements, including OCS pole foundations and downguys, and 3-foot minimum horizontal separation from other structures
  - Maintain 3 feet minimum vertical separation from drainage pipes

The above clearances are minimum requirements. The Designer shall verify the adequacy of these standards.

Electrical and communication lines within the Authority's right-of-way must comply with the above requirements except that a concrete encased duct bank can be used in lieu of steel casing pipe. All underground electrical utilities and supporting facilities within the planned construction area must meet the minimum clearance requirements as defined in CPUC GOs.

9.5.5.1 Underground Utilities within At-Grade Section

Where a portion of the utility line crosses under tracks or is located within 45 feet of the nearest track centerline, the utility shall be encased. The casing under the track shall be a minimum of 6 feet below top of rail and a minimum of 3 feet below the flow line of the ditch or drainage pipe next to the track. Refer to Standard and Directive Drawings for utility clearance requirements. When the utility or portions of it do not come closer than 45 feet from the nearest CHST track centerline, requirements for encasement and burial depths shall be determined on a case-by-case basis.

Casing pipes shall not be less than 6 feet below top of rail and at the closest point. Deeper installations may be required to avoid conflicts with the Systems' under track conduits and buried facilities. Where the pipe is not directly beneath the trackbed, the depth of ground cover shall not be less than 4 feet. A 6-inch-thick layer of reinforced red concrete shall be placed over the casing pipe if 3 feet of ground cover cannot be provided between top of casing pipe and bottom of ditch.

9.5.5.2 Underground Utilities within CHST Systems' Facility Sites

Utilities located within the CHST Systems' facility sites, such as traction power facility and communications' tower sites, shall be relocated outside of the Authority's right-of-way.

9.5.5.3 Underground Utilities within Passenger Station Parking Lots

Underground utilities in parking areas shall have a minimum of 3 feet cover over casings. Additional cover shall be provided where necessary to comply with the utility owner's standards.

9.5.5.4 Underground Utilities within CHST Aerial Structure Section

Underground utilities within 5 feet of a HST pier or abutment foundation shall be relocated in accordance with the requirements of this chapter and the utility owner's clearance requirements. Existing utilities that do not need to be relocated shall be encased in accordance with the requirements of this chapter with the following exceptions:

- Where utilities are within a jurisdictional authority's roadway or railroad's right-of-way.
- Casings do not need to be designed per Cooper E-80 loading requirements but are subject to site specific loading requirements.

Access manholes to utilities shall be relocated outside Authority's right-of-way unless such manholes are located within roadways or access roads of other jurisdictional authorities.

Designer shall submit a utility protection and monitoring plan for utilities within the zone of influence of excavation limits to the utility owner for review and approval.

9.5.5.5 Underground Utilities within CHST Trench Section

Where a trench section is 8 feet or less from the original ground, the utilities shall cross under trench sections in casing and top of casing shall be a minimum of 8 feet below top of rail.

Where a trench section is deeper than 8 feet, utilities shall cross over the trench section in a utility bridge that spans the entire width of trench section. The minimum clearance from the bottom of bridge structure shall be per requirements of the *Trackway Clearances* chapter and the Standard and Directive Drawings for trench sections.

In all other cases, the utility shall be relocated so that the utility crossing can satisfy one of the conditions stated above.

9.5.5.6 Underground Utilities within CHST Tunnel Section

For utility clearance requirements within a tunnel section, refer to Standard and Directive Drawings for tunnel sections.

9.5.5.7 Overhead Utilities

Overhead utilities shall cross the tracks at local, street, or highway overpasses. Such utilities shall either be contained within the overpass structure, or if attached to the outside of the overpass structure, shall be encased in a steel casing sleeve, which shall be grounded and bonded in accordance with the *Grounding and Bonding Requirements* chapter. Where electrical lines with voltage less than 30 kV and communication lines cannot be accommodated in an overpass structure, they shall be relocated underground per clearance requirements established in this chapter. Clearances for overhead electrical lines with voltage higher than 30 kV shall be governed by CPUC GO No. 95 or National Electrical Safety Codes wire to wire clearance requirements, whichever is more stringent, and shall be modified to a higher class of construction:

- Aerial utility facilities shall have the supporting poles, towers, and guys located outside the Authority's right-of-way. Where such condition is impractical, a design variance shall be submitted to the Authority.
- At the span, where the wires cross the OCS conductors, the utility shall be double-dead-ended to avoid a single point of failure so that the wires are not dropped onto the tracks.

9.5.5.8 Aboveground Utility Facilities

All above ground utilities shall be moved outside the Authority's operating right-of-way or conform to the requirements of Sections 9.5.5.1 to 9.5.5.5.

9.5.6 Safety and Protection Measures

Emergency response access and procedures shall be developed to handle a situation in which a pipeline leak or railroad derailment or incident may jeopardize the integrity of the pipeline. Local conditions shall be considered when developing these procedures. Refer to the *Fire Protection* chapter for guidelines.

9.5.6.1 Call Before You Dig

The Designer shall include in its plans the instruction to contact Underground Service Alert and other railroad owners, such as Union Pacific Railroads' "Call Before You Dig" requirements, within the railroad's right-of-way prior to any excavation.

9.5.6.2 Shut-off Valves

Accessible emergency shut-off valve(s) shall be installed as close to the Authority's right-of-way as practicable and as mutually agreed to by the Designer, the Authority, and the utility owner. These valves should be marked with signs for identification. Where there are existing automatic control shut-off valve stations at locations and within distances acceptable to the Authority, additional valve may not be required. Valves shall not be located within the Authority's right-of-way.

9.5.6.3 Utility Markers

Utility markers shall be placed at points where the centerline of the utilities intersects the boundaries of the right-of-way line as they enter and exit the Authority's right-of-way.

Markers shall identify each utility, its owner, CHST milepost, and depth. Markers shall consist of a metal target plate with reflective background mounted on a metal post.

The front face of the target plate shall be marked as indicated in Standard and Directive Drawings for wayside signage and graphics or as required by the utility owner with the milepost and with a symbol identifying the type of the facility, both reading vertically from top to bottom.

The rear face of the target plate shall be marked with the name of utility owner and telephone number for emergency contact, both reading vertically from top to bottom.

Markers shall be oriented so that the front face is perpendicular to the trackway.

For facility naming conventions, refer to the CHSTP Plan Preparation Manual.

9.5.6.4 Cathodic Protection and Corrosion Control

Corrosion control measures shall be applied to all relocated and new metallic and reinforced concrete underground utilities. These measures should include: protective exterior coating, electrical continuity of pipes, electrical isolation of new and existing pipes, cathodic protection and test facilities as appropriate. Soil and groundwater corrosive characteristics shall be determined and documented during the Baseline Corrosion Survey. Analysis of soil boring samples obtained during geotechnical survey shall supplement on-site measurements and shall be the basis for corrosion control design. Corrosion protection of carrier pipes and casings should be in accordance with AREMA MRE 2010 section 5.2.3.3 and the *Corrosion Control* chapter.

In addition, to minimize the possibility that utility pipelines become part of the Traction Power Return System, insulated joints or couplings shall be installed at or adjacent to the shut-off valves or at a similar location if shut-off valves are not required.

9.5.7 Miscellaneous Utilities and Supporting Facilities

9.5.7.1 Railroad Utilities

Signals and communication lines belonging to railroad companies may be affected by construction of the CHSTP. The design and rearrangement of such utilities and supporting facilities that conflict with CHST shall be performed by the facility owner in accordance with owner's standards.

Where CHST utilities and supporting facilities impact railroad utility facilities or where rearrangement of other utility facilities will impact or potentially affect the operation of railroad utility facilities, the Designer shall coordinate its work with the Authority so that adequate data can be furnished to the railroad to complete its work. The Designer shall include the rearrangement of railroad utilities in the utilities plan.

9.5.7.2 Street Lights and Traffic Control Devices

Traffic control devices and street lighting facilities belonging to municipal agencies may be affected by construction. Any facility affected or impacted by the construction shall be replaced in-kind, unless otherwise indicated in the agreement between the Authority and the affected agencies. Refer to the *Civil* chapter for traffic signals design.

9.5.7.3 Fire Alarm and Police Communication Systems

Protection, relocation, and support-in-place of the fire alarm and police communication systems within construction limits shall be in strict conformance with the current standards of the governing agency or municipality.

The Designer shall indicate which emergency communication lines are to be maintained complete in-place, removed, protected and supported, temporarily relocated and replaced after construction is complete. The lines to be abandoned or are already abandoned shall also be indicated.

9.5.7.4 Vaults

Private vaults surrounding the project area that do not encroach upon the Authority's right-of-way shall be protected in place. Vaults that are found to be in conflict with the proposed construction shall be subject to demolition and/ or relocation.

Relocation, abandonment, or other work involving private vaults extending from adjoining buildings into public space shall be in accordance with rules, regulations, and practices of the governing agency, which shall include the city building codes, electric codes, plumbing codes, and ANSI C2, National Electrical Safety Code. Locations and dimensions of vaults affected by the project shall be verified. Quantities and types of goods or facilities including utility services

to be removed from the vault should be verified; the process of deliveries to properties when existing vault entrances require abandonment; and the construction time required to make alterations and occupy the vault shall be determined and incorporated into the design. This information shall be presented to the vault owner, through the Authority, which will arrange for permission to occupy the vault to make the necessary alterations.

Chapter 10

Geotechnical

Revision	Date	Description
0	13 Mar 12	Initial Release, R0
0.1	07 Dec 2012	Addendum 7- CP01

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Appendix

Appendix 10.A: Guidelines for Geotechnical Investigations
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Acronyms

AASHTO	American Association of State Highway and Transportation Officials
Authority	California High-Speed Rail Authority
BDS	Bridge Design Specifications
Caltrans	California Department of Transportation
CBC	California Building Codes
CEG	Certified Engineering Geologist
CGS	California Geological Survey
CHSTP	California High-Speed Train Project
CPT	Cone Penetration Test
CPT_u	Cone Penetration Test with pore pressure measurements
FLH	Federal Lands Highway
GBR	Geotechnical Baseline Report
GBR-B	Geotechnical Baseline Report for Bidding
GBR-C	Geotechnical Baseline Report for Construction
GDR	Geotechnical Data Report
GEDR	Geotechnical Engineering Design Report
GIP	Geotechnical Investigation Plan
GTGM	Geotechnical Technical Guidance Manual
HST	High-Speed Train
IGM	Intermediate Geomaterials
LOTB	Logs of Test Borings
LRFD	Load and Resistance Factor Design
MASW	Multichannel Analysis of Surface Wave
M-O	Mononobe-Okabe
MCE	Maximum Considered Earthquake
OBE	Operating Basis Earthquake
OCS	Overhead Contact System
PDA	Pile Driving Analyzer
PDDM	Project Development Design Manual
PGA	Peak Ground Acceleration
SASW	Spectral Analysis of Surface Waves
SSI	Soil-Structure Interaction
USGS	United States Geological Survey

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10 Geotechnical

10.1 Scope

This chapter provides guidance, geotechnical criteria, and requirements for the geotechnical engineering design for earthwork, embankments, and bridges/aerial structures, abutments, underground structures, and culverts for the California High-Speed Train (HST) trackway.

10.2 Regulations, Codes, Standards, and Guidelines

Refer to the *General* chapter for requirements pertaining to regulations, codes, and standards. Elements of HST infrastructure, based on their importance to HST, shall be classified as Primary Type 1, Primary Type 2, and Secondary. Definitions of these elements can be found in the *Seismic* chapter. Design of geotechnical work specified in this chapter applies to Primary Type 1 and Type 2 structures, while the Secondary structures are designed according to the requirements set forth in the jurisdiction of the local County, City, or third party.

Geotechnical design work, in general, shall be in accordance with the AASHTO LRFD Bridge Design Specifications (BDS) with State of California Caltrans Amendments, these geotechnical design criteria, and the requirements of the following standards:

- American Association of State Highway and Transportation Officials (AASHTO) Guidance
  - AASHTO Guide Specifications for Design and Construction of Segmental Concrete bridges
  - AASHTO Guide Specifications for Thermal Effects in Concrete Bridge Superstructures
- California Department of Transportation (Caltrans)
  - Caltrans Seismic Design Criteria (CSDC)
- California Building Code (CBC)
- American Society of Civil Engineers (ASCE), Geotechnical Baseline Reports for Construction – Suggested Guidelines, prepared by Essex, 2007
- Federal Highway Administration (FHWA) Guidelines
  - FHWA Project Development and Design Manual (PDDM)
  - FHWA Drilled Shaft Construction Procedures and LRFD Design Methods, FHWA-NHI-10-016
  - Technical Manual for Design and Construction of Road Tunnels – Civil Elements, FHWA-NHI-09-010

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- – FHWA Drilled Shafts: Construction and Procedures and Design Methods, FHWA-IF-99-025
- – FHWA Mechanically Stabilized Earth Walls and Reinforced Soil Slope Design and Construction Guidelines, FHWA-NHI-00-043
- – FHWA Earth Retaining Structures, FHWA-NHI-99-025
- – FHWA Soil Slope and Embankment Designs, FHWA-NHI-01-026
- – FHWA Rock Slopes Reference Manual, FHWA-HI-99-007
- – FHWA Geosynthetics Design and Construction Guidelines, FHWA HI-95-038
- – FHWA Geotechnical Instrumentation, FHWA-HI-98-034

- National Cooperative Highway Research Program (NCHRP) Report 611; Seismic Analysis and Design of Retaining Walls, Buried Structures, Slopes, and Embankments, Transportation Research Board
- International Union of Railways (UIC) Code 719R Earthwork and Trackbed for Rail Lines (2008)

10.3 General Requirements

The Geotechnical Designer shall be a licensed Geotechnical Engineer in the State of California with a minimum of 15 years of design and practical field experience in geotechnical and seismic engineering related to aerial and underground structures. The Geotechnical Designer shall conduct work necessary to perform supplemental geotechnical investigation and complete the design for the California High-Speed Train Project (CHSTP). The Geotechnical Designer shall develop geotechnical designs and construction excavation support systems in accordance with the requirements set forth in this chapter. Elements of the work include, but are not limited to, the following:

- Review of existing geotechnical information, including but not limited to the Geotechnical Baseline Report for Bidding (GBR-B), the preliminary Geotechnical Data Report (GDR), and the preliminary Geotechnical Engineering Design Report (GEDR).
- Evaluate the requirements of the work and perform additional geotechnical explorations, laboratory testing, and geotechnical analyses to supplement the existing data in support of its final design and proposed means and method of construction.
- Perform additional field testing to measure in situ field shear wave velocity for each geological site and at river crossings, creeks, and locations where compressible soils and high groundwater are expected. Submit the results to the California High-Speed Rail Authority (Authority) for updating final ground motion analyses.

- Prepare final Geotechnical Data Report (GDR) and Geotechnical Engineering Design Report (GEDR), and Geotechnical Baseline Report for Construction (GBR-C) as stated herein.
- Perform professional engineering support of the final structural design and design of temporary support works.
- Perform construction inspection and provide construction support to the Contractor related to geotechnical related works.

The Geotechnical Designer shall prepare the Geotechnical Reports in accordance with the criteria set forth in this chapter. Geotechnical work shall be conducted under the direction of the Geotechnical Designer. Geotechnical reports, calculations, and drawings shall be initialed and stamped by the Geotechnical Designer. In addition, the Geotechnical Designer shall be responsible for the following:

- Overseeing geotechnical design and construction support of bridges, embankments, retaining walls, roadways, tunnels, underground stations, roadways, and other geotechnical related facilities.
- Determining if more stringent criteria are appropriate and/or required by applicable codes, manuals, or other references (in addition to those listed). Addressing such criteria as part of the final design.
- Approving construction under his/her design control.

10.4 Subsurface Investigation and Data Analysis

The Geotechnical Designer shall interpret the existing geotechnical data and perform subsurface investigations, field and laboratory testing, fault displacement mapping, and rock slope mapping as may be necessary to satisfy itself as to the nature of the following:

- Soil, rock, groundwater, and subsurface conditions
- The geological and hydro-geological formations and seismic hazards within and attributes of the project site
- Variations in the subsurface and groundwater conditions across the project site and adjacent areas that can potentially be impacted by construction or train operations (e.g., ground movements or estimate of high-speed train induced ground vibration).

In addition, the Geotechnical Designer shall undertake soil resistivity testing. The ability of soils to conduct electricity may have a significant impact on the corrosion of buried structures and the design of grounding systems. Accordingly, subsurface investigations shall include conducting appropriate investigations to obtain soil resistivity values. The following information and methodologies are required:

- Soil resistivity readings shall be obtained to determine the electric conduction potential of soils at each traction power facility (supply/paralleling/switching station) locations, which are spaced at approximately 5-mile intervals.
- Resistivity measurements shall be obtained in accordance with the Institute of Electrical and Electronics Engineers (IEEE) Standard 81-1983 – IEEE Guide for Measuring Earth Resistivity using the four-point method for determining soil resistivity. IEEE states that the four-point method is more accurate than the two-point method.

Appendix 10.A – Guidelines for Geotechnical Investigations provides guidance for the expected level, frequency, and reporting of geotechnical investigation envisioned as necessary to fully satisfy the requirements of the Project.

Interpretations and necessary investigations and testing shall consider the methods of construction, critical combinations of loading, and all other factors impacting evaluation.

A Geotechnical Investigation Plan (GIP) shall be prepared by the Geotechnical Designer to supplement and update existing subsurface information available for final design of the structures. The investigation shall follow *Appendix 10.A – Guidelines for Geotechnical Investigations.*

The plan shall include the criteria or rationale used in developing the plan and shall identify locations of explorations, together with their depths, sampling intervals, and a description of both the field and laboratory testing program utilized. This plan shall be submitted to the Authority prior to commencing geotechnical investigations.

The requirements for the field and laboratory investigations to be performed by the Geotechnical Designer shall be the following:

- Perform additional subsurface investigations to supplement existing geotechnical data for the design of elements along the proposed alignment.
- Supervision – Boring and in-situ testing and inspection, and laboratory classification and testing, shall be performed by California licensed geologists or geotechnical engineers under the direct supervision of a design professional licensed in California with a minimum of 10 years experience in the performance and supervision of geotechnical investigations.
- Location and Ground Surface Elevation – The Geotechnical Designer shall determine the coordinate location and ground surface elevation for each boring and field investigation site, and shall show the coordinates, and station and offset, and the elevation for each individual boring log or investigation record. Coordinates and station and offset shall be referenced to the Project survey control. Elevations shall be referenced to the CHSTP datum and horizontal control system.
- Laboratories shall be Caltrans certified and equipment used for field testing shall have documentation of calibration within the last year.

- Information obtained using a pocket penetrometer or field torvane shall not be relied upon as the primary means for development of geotechnical parameters.
- Soil samples and rock cores shall be kept and maintained in a readily accessible storage facility within 100 miles of the project site during construction. No disposal of the soil samples and rock cores shall be made until it is instructed by the Authority after completion of the project. These samples shall be available for viewing by the Authority or its designees within two business days of a request. Untested samples shall not be disposed of or released to a third party at any time without the written authorization of the Authority.
- For rock slopes, tunnels through rock within 15 feet above the tunnel crown and 10 feet below the tunnel invert, and rock excavations at the portals and substructures, oriented cores with down hole camera logging shall be performed to obtain structural geological parameters such as orientations (dip/strike), roughness, infilling, spacing, etc. of structural discontinuities (bedding, joints, fault zones, shear zones, breccias, etc.)
- Borehole Site Cleanup – Backfilling of borings, test pits, Cone Penetration Tests (CPTs), rotosonic holes, wells, and probe holes shall be performed in accordance with the provisions of applicable local, state, or federal laws and regulations, and permit requirements. Restoration of pavement shall be performed in accordance with street use permit requirements.
- Test holes shall be backfilled in a manner that ensures against subsequent settlement or heave of the backfill. Upon completion of field investigations, surplus materials, temporary structures, and debris resulting from the drilling work performed on land and in water shall be removed and disposed of from the site.
- Final boring and rock core logs shall be prepared using gINT Geotechnical and Geoenvironmental software.
- No geological/hydro-geological data and seismic hazard evaluation results shall be released to a third party without the approval of the Authority.

10.5 Geotechnical Reports

Geotechnical reports including the GDR, GEDR, and GBR-C shall be prepared, signed, and stamped by the Geotechnical Designer.

10.5.1 Geotechnical Data Report (GDR)

Geotechnical investigation of the subsurface conditions, including laboratory and field testing, shall be performed to describe the geologic features of the project area. A summary of geotechnical data and findings, including a summary of existing information and that of the preliminary design level of subsurface investigation, results of the final field subsurface investigations including mappings, if any; and laboratory testing data, shall be prepared as the

GDR. The GDR shall contain factual information that has been gathered in the preliminary design of subsurface investigations and the final subsurface investigations. The GDR shall contain the following information:

- Project description
- Description of desk study results gathered from existing available data
- Description and discussion of the site exploration program
- Locations and results of subsurface investigations (borings, CPTs, Geophysical Testing, etc.) including photo documentation of core hole core samples and investigation sites.
- A detailed description of geological and subsurface conditions (including a description of site stratigraphy, geologic hazards, and groundwater conditions)
- Rock parameters including orientation and nature of jointing, bedding, etc.
- Description of surface water (springs, streams, etc.) and groundwater conditions
- Seismic setting including location of nearby faults
- Boring and rock core logs with soil descriptions and field test results
- Groundwater level measurements from monitoring wells and piezometers
- Ground movement measurements from inclinometers
- Description and results of field/in situ testing and rock mapping
- Description and results of laboratory tests
- Material properties
- Chloride content, acidity (pH value) and sulfate content of the surface water, groundwater, and soils
- Statistical analysis for test results per geotechnical layer
- Results of field and laboratory testing
- Logs of borings, CPTs, trenches, and other site investigations
- Standards for laboratory and field testing

10.5.2 Geotechnical Engineering Design Report (GEDR)

The findings and evaluations of subsurface data along with geotechnical and foundation analyses and design recommendations shall be documented in the form of a GEDR which serves as the basis for final geotechnical design. The GEDR shall include, but is not limited to, the following:

- Project description including surface conditions and current use
- Regional and site geology

- Regional and site seismicity
- A summary of subsurface explorations, including field and laboratory testing, and locations (map with coordinates) of borings, wells, and other in-situ testing sites
- Detailed description of geological and subsurface conditions (including a description of site stratigraphy) along with geological profile and cross-sections
- Seismic design criteria including design earthquake, magnitude, and peak ground and bedrock acceleration
- Evaluation of seismic and geologic hazards including, but are not limited to, liquefaction/lateral spreading, pre-historic landsliding and ground subsidence due to long-term pumping of groundwater or withdrawal of petroleum and gas, if any
- Subsurface material properties
- Data and complete discussions of geotechnical analyses, designs, and studies.
- Recommended design parameters for soil and rock types
- Conclusions and recommendations for foundation types for structures (with appropriate design parameters), soil and rock cut slopes, fill embankments, retaining walls, requirements for backfill materials
- Potential groundwater impact and dewatering requirements
- Instrumentation and monitoring requirements during and after construction
- Potential settlement/horizontal deflection problems and mitigation measures
- Potential soil and rock slope and retaining wall stability problems and analysis results along with mitigation measures
- Anticipated ground behavior and categorization of ground during excavation, filling and foundation, and retaining structure construction; particular attention shall be paid to identifying and mitigating impacts due to excavating near the groundwater table.
- Blasting and excavation methods as related to the design of cut slopes, including a discussion of blast design parameters that are related to the geotechnical conditions
- Consideration for, discussion of, and rationale for protection of existing structures, water bodies, and environmentally or historically sensitive areas
- Discussion on induced vibration and noise from the selected construction equipment and procedures and the effects on adjacent structures and landowners
- Evaluation of in-situ stress conditions (if applicable)
- Evaluation of load bearing capacity of the encountered soil/rock types
- Stability analyses in agreement with applicable codes and standards
- Evaluation, if excavated material can be used as fill/backfill material

- Geotechnical recommendations including earthwork/sitework; ground stabilization for foundation support; stabilization of unstable soil and rock slopes; and foundation options for aerial structures, underground structures, retaining walls, hydraulic structures, and other structures
- Construction considerations given to issues related to construction staging, shoring needs, potential installation difficulties, temporary slopes, earthwork constructability issues, dewatering, etc.
- Long-term and construction monitoring needs

10.5.3 Geotechnical Baseline Report for Construction (GBR-C)

A Geotechnical Baseline Report for Construction (GBR-C) shall be developed, upon completion of subsurface investigations, to verify design assumptions and finalize the design. As part of the final design and construction planning process, the Geotechnical Designer shall interpret the various baselines expressed in the GBR-B, consider those baselines in the development of the design and construction approaches, and fill in any missing information in the GBR-B accordingly. An electronic form of the GBR-B shall be used to record modifications or clarifications in the track-change mode of a computerized word processing software program. In its completed form, the GBR-C will serve as the physical baselines established by the Authority and the Contractor as well as the behavioral baselines described by the Contractor consistent with its design approach, equipment, means and methods.

The GBR-C shall include, but is not limited to, the elements listed in the "Geotechnical Baseline Reports for Construction – Suggested Guidelines" prepared by ASCE (Essex, 2007). The GBR-C shall be limited to interpretive discussion and baseline statements, and shall make reference to information obtained in the Geotechnical Data Report (GDR), Geotechnical Baseline Report for Bidding (GBR-B), drawings, and specifications.

10.6 Aerial Structure / Bridge Foundations and Stations / Miscellaneous Structures

Foundation design shall be based on project-specific information developed for the location(s) and foundation type planned. It shall be carried out in accordance with the AASHTO Specifications or other Standards or Codes referred to in Section 10.2 of this chapter provided that these are comparable and equivalent to or complement AASHTO Specifications, and as modified below. For structures subject to the jurisdiction of local authorities, soil parameters, such as design bearing and frictional values for foundations, shall not exceed the limits given by the local building codes, except for deviations as provided for in the codes.

10.6.1 Geotechnical Data

Type and depth of foundations shall be determined from available geotechnical data and additional geotechnical investigations at the locations of the foundations. Use of presumptive values shall not be allowed for final design.

Foundations in rivers and creeks shall take into consideration flood levels and maximum scour depth as determined by the *Drainage* chapter.

10.6.2 Load Modifiers, Load Factors, Load Combinations, and Resistance Factors

The design shall be in accordance with the concepts and general methodology of AASHTO LRFD BDS with Caltrans Amendments. See the *Structures* chapter for load factors and load combinations. Load resistance factors walls and shafts shall be in accordance with AASHTO LRFD BDS with Caltrans Amendments.

10.6.3 Allowable Foundation Settlements and Displacements

Requirements for tolerable foundation settlements and displacements presented herein shall supersede criteria indicated in AASHTO LRFD BDS with Caltrans Amendments. For deep foundations, allowable settlements or displacements are measured at the top of the foundation (i.e., the pile cap, pile head, or the ground surface for drilled shaft pier-extensions). For structure foundations, settlements calculated from the Service 1 load combination plus any settlements resulting from the Operating Basis Earthquake (OBE) load combination (such as those resulting from post-liquefaction downdrag, seismic compaction, etc.) shall not exceed the settlement limits denoted in Table 10-1. For approach embankments, the Service 1 settlement limits and OBE load combination are applicable to settlements that occur after the placement of track.

Table 10-1: Maximum Settlement Limits [4] for Service 1 and OBE Load Cases

Settlement Criteria	Non-Ballasted Track	Ballasted Track
Differential Settlement Between Adjacent Supports [1]	≤ L/1500 (L = smaller span in inches), but no greater than 3/4 inch	N/A [3]
Differential Settlement Between Abutment and Approach Embankment [2] [5]	≤ 3/8 inch over 62 feet	≤ 3/4 inch over 62 feet
Differential Settlement Between Abutment and Tunnel Portal [5]	≤ 3/8 inch over 62 feet	N/A [3]
Uniform Settlement at Piers and Abutments	≤ 3/4 inch	N/A [3]

Notes:

(1) The additional forces imposed on the structural system by differential settlements shall be calculated and considered as part of dead load in the design.

(2) Embankment shall be instrumented and monitored for a period of at least 12 months following completion of the structure. The Geotechnical Designer shall demonstrate future compliance with the residual settlements by extrapolation from the monitored data.

(3) Not applicable based on the assumption that ballasted track will not be used for bridges, aerial structures, or tunnels.

(4) The settlements calculated from the Service 1 load combination plus any settlements resulting from the OBE load combination (such as those resulting from post-liquefaction downdrag, seismic compaction, etc.).

(5) Differential settlement shall be measured along the track (surface profile uniformity) in the vertical plane of each rail at the mid-point of a 62-foot long chord.

Refer to the *Structures* chapter's section on Track-Structure Interaction for additional performance requirements for allowable deformations for the track

No specific settlement or displacement limits are required for the Extreme Event Maximum Considered Earthquake (MCE) loading case, only that the structure shall not collapse and that foundation element are capacity protected in accordance with the *Seismic* chapter.

10.6.4 Aerial Trackway Foundations

Aerial trackway structure and bridge foundations shall be either shallow or deep foundations.

10.6.4.1 Shallow Foundations

Shallow foundations shall be spread footings, combined footings, or mat foundations. They shall be used where there is competent bearing layer near the surface, no highly compressible layers below, and calculated settlements are within acceptable limits outlined in this chapter.

Geotechnical design of abutment and bent/pier shallow foundations shall be carried out in accordance with AASHTO LRFD BDS with Caltrans Amendments, Articles 10 and 11, and as supplemented in this chapter. Unless otherwise specified, see the *Structures* chapter for LRFD load factors and load combinations.

Geotechnical design of retaining wall shallow foundations shall be carried out in accordance with Section 10.7 of this chapter, AASHTO LRFD BDS with Caltrans Amendments Articles 10 and 11, and as supplemented in this chapter. See the *Structures* chapter for LRFD load factors and load combinations and this chapter for additional three service load conditions.

A. Bearing of Soil/Rock

The nominal bearing resistance for shallow foundations shall be determined based on existing available geotechnical data and the geotechnical subsurface conditions of the foundation soil or rock. For all types of shallow soil foundations, the factored uniform bearing stress at the strength limit state, based on the effective footing dimension method in accordance with AASHTO LRFD BDS with Caltrans Amendments Articles 10.6.1.3 and 11.6.3.2, shall not be greater than the factored nominal bearing resistance. For all types of shallow rock foundations, the factored bearing stress at the strength limit state, based on the linearly distributed pressure method in accordance with AASHTO LRFD BDS with Caltrans Amendments, Article 11.6.3.2, shall not be greater than the factored nominal bearing resistance.

For abutment shallow soil/rock foundations, the bearing stress at the Service 1 limit state, based on the linearly distributed pressure method, shall not be greater than the site specific nominal bearing resistance according to AASHTO LRFD BDS with Caltrans Amendments.

B. Stability

The entire soil bearing area under the shallow foundations shall remain in compression at all times under the normal loading condition (1).

Under exceptional loads (2), the soil pressure distribution at the base shall have a compression width of at least 2/3 of the foundation width.

Under ultimate loads (3), the soil pressure distribution shall have a compression width of at least 1/2 of the foundation width.

Notes:

(1) Normal Loads $= DC + DW + L + CF + E + WA + LF_2 + 0.6TU$

(2) Exceptional Loads $= DC + DW + L_1 + CF_1 + LF_1 + E + WA + WS + WL_1$

$= DC + DW + L_1 + CF_1 + LF_1 + E + WA + OBE$

(3) Ultimate Loads $= DC + DW + E + WA$ (buoyancy only) $+ MCE$

For loading definitions, refer to the *Structures* chapter.

DC	=	Dead load of structural components and permanent attachments
DW	=	Dead load of non-structural components and non-permanent attachments
CF	=	Centrifugal force (multiple trains)
CF_1	=	Centrifugal force (single train)
E	=	Earth pressures, including EV, EH, and ES
L	=	Multiple trains of LLRR or LLV, whichever governs
L_1	=	Single train of LLRR or LLV, whichever governs
LF_1	=	Braking forces (apply braking to one train) for LLV loading
LF_2	=	Acceleration and braking forces (apply braking to one train, and acceleration to the other train) for LLV loading
MCE	=	Maximum Considered Earthquake (refer to the *Seismic* chapter)

OBE	=	Operating Basis Earthquake (refer to the *Seismic* chapter)
TU	=	Uniform temperature effects
WA	=	Water loads, including stream flow and buoyancy,
WS	=	Wind load on structure
WL_1	=	Wind load on one train

C. Allowable Foundation Settlements and Displacements

Total settlements and differential settlements of shallow foundations under the service limit state shall not exceed those specified in Table 10-1. See the *Structures* chapter for service limit state load combinations.

D. Benching

Where footings are to be constructed on inclined surfaces with slopes greater than 1 Vertical: 10 Horizontal (1V:10H), the surface shall be benched (Section 10.8.4).

E. Bottom of Footings

The depth of footings shall be determined based on the characteristics of the foundation materials and in consideration of the possibility of undermining. Footings not exposed to the action of stream or river current shall be founded on firm foundation below the frost level or a firm foundation that is made frost resistant by over excavation of frost-susceptible material below the frost line and replaced with material that is not frost susceptible.

In cases where spread footings are used in streams and rivers, the following additional design requirements shall be considered:

- Footings on Soils – The bottom of footings on soils shall be set at least 10 feet below the river bottom unless otherwise stated in this chapter. The potential shift of the stream or river channel shall be considered when determining the channel bottom. The top of footings on soil shall be below the total scour depth determined for the 100-year flood, and the bottom of footings on soil shall be below the estimated depth of the check flood (500-year) scour elevation.
- Footings on Rock –The bottom of footings shall be at least 3 feet below the surface of scour-resistant rock (i.e., rock not subject to scour attack) with the top of the footings at least below the rock surface.
- Footings on Erodible Rock – The foundation design of footings on erodible rock shall be based on:
  - Assess weathered rock or other potentially erodible rock formations for scour.
  - An analysis of intact rock cores, including rock quality designations and local geology, hydraulic data, and anticipated structure life.

10.6.4.2 Deep Foundations

Deep foundations shall be bored or driven piles and Cast-in-Drilled-Hole (CIDH) piles (also known as drilled shafts). These shall be used when shallow foundations cannot be used to carry the applied loads safely and economically and meet the required settlement criteria. Alternative deep foundation systems such micropiles, rammed aggregate piers, and propriety systems shall not be allowed for support of aerial structures and bridges.

The top of deep foundations, including top of drilled shafts or pile caps where multiple shafts or piles are employed, shall be a minimum of 3 feet below the lowest adjacent finished grade.

A. <u>Ultimate Pile Load Capacities</u>

The ultimate pile axial capacity shall be determined based on appropriate values of skin friction plus end bearing developed from the results of site-specific geotechnical investigations, and shall be verified by test piles and load testing as described herein.

The adequacy of the bearing capacity of the drilled shafts and bore or driven piles shall be verified regarding (1) the factual soil parameters at the respective locations and depth of the foundations, and (2) the groundwater table. Refer to Section 10.6.4.3 on Test Piles and Load Tests for verification of assumptions for deep foundation design.

Pile foundations shall be designed in such a way that plastic hinges do not occur in the piles.

B. <u>Settlements and Horizontal Displacements</u>

Total settlements of deep foundations shall not exceed those specified in Table 10-2. These values shall be verified. Piles/drilled shafts and connection to pile caps shall be checked for the estimated deflection from the lateral load. Tolerable lateral deflection shall be no greater than 1/2 inch.

For deep foundations, soils exhibiting potential liquefaction and lateral spreading in an earthquake, ground improvement may be considered to improve the foundation stability. Where ground improvement measures are prohibitively costly and impractical, consideration shall be given to designing a combined system composed of improved ground and strengthening of the foundation.

C. <u>Lateral Load Capacity</u>

Piles and drilled shafts shall be designed to adequately resist lateral loads transferred to them from the structure without exceeding the deformation which creates a stress outside the allowable stress range of the structure or overstressing the foundation elements. The lateral load resistance of the individual and group of piles and drilled shafts shall be analyzed. The analysis shall consider nonlinear soil pressure-displacement relationships, soil-structure interaction, group action, groundwater, and static and dynamic load conditions. The performance of the piles and drilled shafts shall include determination of vertical and horizontal movements, rotation, axial loads, shear, and bending moment for the foundation elements.

The lateral load capacity of piles and drilled shafts shall be verified by means of pile load tests in the field as described herein.

D. Wave Equation Analyses

The constructability of a pile design and the development of pile driving criteria shall be performed using a Wave Equation Analysis for Piles (WEAP) computer program in accordance with AASHTO Standard Specifications for Highway Bridges. Analysis shall be conducted for hammers and pile types proposed for use and for each bridge foundation. Wave equation analysis shall not be used as the sole basis for determining pile capacity or pile acceptance.

E. Pile Group Effects

Generally for piles or drilled shafts constructed in groups, the spacing of pile centers shall not be less than 2.5 pile diameters (or pile size). Piles or drilled shafts in any one group shall be of the same diameter. Pile group effects shall be considered with regard to the bearing capacity, settlement, and lateral resistance.

Multiple rows of piles/drilled shafts will have less resistance than the sum of the single individual piles/drilled shafts because of pile-soil-pile interactions that take place in the pile group (also called shadowing effect). The shadowing effect results in the lateral capacity of the pile group being less than the sum of the lateral capacities of the individual piles comprising the group. Consequently, lateral loaded pile groups will have group efficiencies less than unity, depending on the pile spacing.

When the P-Y method of analysis is used to evaluate a lateral loaded pile group, reduce the values of P by a multiplier (P_m) as shown in Table 10-2.

Table 10-2: Pile Load Modifiers, P_m, for Multiple Row Shading

Pile Center-to-Center Spacing (in direction of loading)	Pile Load Modifiers, P_m		
	Row 1	Row 2	Row 3 and Higher
3D	0.75	0.55	0.40
5D	1.0	0.85	0.7
7D	1.0	1.0	0.90

F. Down Drag (Negative Skin Friction) Effects

The design of piles and drilled shafts shall take into consideration the effect of negative skin friction as induced by dewatering, liquefaction, construction of embankments or from pile installation methods. When down drag (negative skin friction) is considered, it shall be treated as an addition to the nominal loads.

The nominal pile resistance available to support the downdrag and nominal loads shall be estimated by considering only the positive side and tip resistance below the lowest layer contributing to downdrag (i.e., neutral plane[1]). If measures are proposed for reducing the effect of negative skin friction by means of a slip coating (e.g., bitumen, geotextile coating, etc.), then consideration shall be given to the long term value of residual negative skin friction that may develop. Instrumented pile load tests and dynamic tests shall be undertaken to verify design assumptions and to estimate the available nominal resistance to withstand the downdrag plus the nominal loads.

G. <u>Uplift</u>

Friction piles may be designed to resist uplift in non-liquefiable soils in accordance with recommendations in the GEDR. Resistance factors are per AASHTO LRFD BDS with Caltrans Amendments.

Should any loading or combination of loadings produce uplift on any pile, the pile to pile cap or pile to invert slab connection or footing shall be designed to resist uplift forces and other tension zones caused by the uplift condition.

H. <u>Scour</u>

For design of deep foundations to support bridges and aerial structures, geotechnical analyses shall be performed assuming that the soil above the estimated scour line based on the 100-year flood has been removed and is not available for bearing or lateral support.

10.6.4.3 Test Piles and Load Tests

A. <u>Indicator Piles/Test Piles, Method Test Shafts and Load Test Shafts</u>

An adequate number of indicator piles (1), test piles (2) and method test shafts (3)/load test shafts (4) shall be specified. These shall include advanced test piles/shafts tested to ultimate load to verify design assumptions. The locations and length of the indicator/test piles and method shafts/load test shafts shall be shown on the plans. Indicator piles/test piles and method test shaft/load test shafts shall be located to cover conditions of pile type, sizes, pile/shaft capacity, and soil conditions which will be encountered. Test piles that pass the load test in an undamaged condition may be utilized as production piles in the work. However, method test shafts/load test shafts shall be considered sacrificial and shall not be used as production drilled shafts.

[1] Neutral plane is the location where the downward acting forces are equal to the upward acting forces and where there is no movement between the pile and the soil. At this location, the pile and the soil settle equally.

Notes:

[1] Indicator Pile – An individual pile that is tested and observed to determine its behavior during driving.

[2] Test Pile – An individual pile that is tested and observed under static axial compressive or tension load, under lateral load, and under dynamic load tests.

[3] Method Test Shaft – A drilled shaft that is excavated to verify construction methods so that drilling and support of excavation can be evaluated for each site.

[4] Load Test Shaft – A method test shaft with reinforcing placed, any casing or other excavation support system withdrawn, and full concrete placement, followed by gamma ray testing or crosshole sonic testing to verify concrete placement. Method test shaft is then observed under static axial compressive or tension load, under lateral load and under dynamic load tests.

As a minimum, indicator piles, test piles, and method test shafts shall be located on the following basis:

- One indicator pile and one test pile per 300 driven piles.
- One indicator pile and one test pile at each pile location separated by a distance of 500 feet or less from other indicator pile/test pile locations.
- One method test shaft per 50 drilled shafts.
- One method test shaft and one load test shaft at each shaft location separated by a distance of 500 feet or less from other method test shaft/load test locations.
- Test programs as indicated elsewhere in this chapter.

B. Load Tests

An appropriate number of deep foundations (driven piles and drilled shafts) shall be tested to ultimate or design loads to verify design assumptions. The location and length of the test deep foundations shall be such that they will cover conditions of types and capacity of the deep foundations as well as soil conditions which will be encountered. These load tests shall be conducted on test piles, method test shafts, and production piles/drilled shafts.

Load tests, if conducted, may be used to increase the resistance factor that is specified in AASHTO Standard Specifications for Highway Bridges. Loading test methods shall be in accordance with the technical specifications applicable to the Contract. In general, static load test capacity of piles shall be tested for compressive, lateral, and tensile loads in accordance with the following ASTM International Standards:

- ASTM D1143, Test Method for Deep Foundations Under Static Axial Compressive Load
- ASTM D3966, Test Method for Deep Foundations Under Lateral Load
- ASTM D3689, Test Method for Deep Foundations Under Static Tensile Load

Alternative load test methods such as Standard Test Method for High Strain Dynamic Testing of Piles (ASTM D4945), Osterberg Cells, Statnamic Load Test (ASTM D7383), etc., may be used.

However, these substitutive test methods shall be verified by a conventional loading test of similar piles or drilled shafts.

Drilled Shafts – An adequate number of load tests shall be specified in the following. These shall include Load Test Shafts tested to ultimate load (load tests) to verify design assumptions. The locations and length of the test shafts shall be shown on the plans. Method test shafts shall be located to cover the shaft type, shaft capacity, and soil conditions which will be encountered.

The Geotechnical Designer shall perform a test shaft program consisting of method test shafts (1) to confirm adequacy of drilling methodology and equipment, and (2) load tests to verify compressive, lateral, and tensile load capacities per site as described in the following. A location is considered to be a different site if any of the following are true:

- The location is more than 2,000 feet from the method test shaft location where the subsurface conditions are similar.
- The geologic character of the predominantly bearing formation and side resistance is different.
- At each of the main piers of a long span (more than 300 feet) bridge where there are a large number of drilled shafts (greater than 8) in each pier foundation, particularly where the geology may differ on either side of a natural drainage feature.
- The average calibrated resistance (unit load transfer in side resistance or end bearing) in the zone providing the majority of the axial resistance varies from the test location by a factor of two or more.
- Sequence, type of construction, and type of shafts are changed.

Once approval has been given to constructing production drilled shafts, no change shall be permitted in the methods and equipment used to construct the satisfactory method test shaft without production of additional method test shafts and written approval of the Geotechnical Designer.

Driven Piles – An indicator pile program consisting of indicator piles, test piles and load tests shall be conducted at each bridge or aerial structure site where driven piles are to be installed. Perform dynamic monitoring using a Pile Driving Analyzer (PDA) on indicator piles conforming to the requirements of ASTM D4945. Perform static load tests to verify compressive, lateral, and tensile loads of individual piles. Indicator piles may be installed as production piles provided PDA test results demonstrate the required capacity is achieved.

To utilize the increase in capacity due to setup in cohesive soils, PDA measurements shall be recorded using Case Pile Wave Analysis Program (CAPWAP) during restrike of piles to determine setup. PDA results and revised criteria for the restrike shall be applied to only the piles in that group. Piles shall be re-struck no sooner than 48 hours after installation.

The Engineer inspecting the PDA testing shall have at least five years of experience in the monitoring of the driving of piles with PDA and in performing analyses with CAPWAP in

similar type of soil conditions. The Engineer performing PDA related analyses shall be a geotechnical engineer licensed in the State of California.

The Geotechnical Designer shall be on-site during PDA testing of initial and restrike pile installation. The Geotechnical Designer shall evaluate data to establish driving criteria for production pile installation.

C. Integrity Testing

Integrity testing consisting of gamma-gamma or Crosshole Sonic Logging (CSL) or both shall be performed on drilled shafts larger than 24 inches in diameter. Gamma-gamma and CSL tests shall be reviewed and approved by the Geotechnical Designer as well as any remedial measures or repairs that may be needed. In addition, integrity testing is required on driven piles. ASTM D5882, Test Method for Low Strain Impact Integrity Testing shall be performed on piles and drilled shafts 24 inches in diameter or more.

10.6.5 Other Design Considerations

10.6.5.1 Foundation Cover

Soil cover over top of foundations of piers or abutments shall have a minimum thickness of 3 feet. In rivers and creeks, the soil cover shall be such that it will be at least 3 feet below the maximum estimated scour depth or at least 10 feet below the river bottom for shallow foundations supported by soils, whichever is the deeper.

In urban areas and adjacent to highways, railroads, transit systems, the elevation at the top of the foundations shall be in compliance with the requirements set forth by the local authorities to allow for adequate depth for utilities and surface drains.

10.6.5.2 Foundation Thickness

Spread footings for piers and abutments shall have a minimum thickness of 3 feet.

The thickness of a pile cap shall be the larger of 3.5 feet or the depth required to develop the full compressive, tensile, flexural, and shear capacity of the pile reinforcement.

10.6.5.3 Piles/Drilled Shafts

Minimum penetration depth of piles and drilled shafts into competent bearing soils shall be 10 feet. In the event that the piles and drilled shafts are embedded in rock, the minimum penetration depth shall vary between 3 feet to 10 feet, varying linearly with the unconfined compressive strength of the rock as follows:

Table 10-3: Minimum Penetration Depth in Rock

Rock Unconfined Compressive Strength (psi)	Embedded Depth (feet)
< 75	10
≥ 750	3

End bearing soil below the pile/drilled shaft tip shall be competent materials, having a thickness of at least 3 x D (where D is either the pile diameter or drilled shaft width) and shall demonstrate the adequacy of resisting punching shear failure and settlements.

10.6.6 Station and Miscellaneous At-Grade Structures

10.6.6.1 Shallow Foundations

Per Caltrans BDS (ASHTO LRFD BDS, Article 10.2 Definitions): "Shallow Foundation – A foundation that derives its support by transferring load directly to the soil or rock at shallow depth."

Design of shallow foundations, e.g., spread and strip footings in addition to mat foundations, shall be based on project-specific information developed for the location(s) and foundation type(s) planned. Soil and rock engineering properties shall be based on the results of field investigations as presented in the Geotechnical Data Report; use of presumptive values shall not be allowed. Designs of shallow foundations supporting rail structures or attached appurtenances shall be as required in Caltrans BDS (AASHTO LRFD BDS, Article 10.6) and in accordance with FHWA-SA-02-054 (Geotechnical Engineering Circular No. 6 Shallow Foundations). Shallow foundations for support of structures under the purview of the Building Code, buildings not directly supported off the aerial trackway structure, shall be designed in conformance with the requirements of the Building Code – Footings and Foundations. Shallow foundations shall have a minimum ground cover of 2 feet as measured from the top of footing to finished grade.

Shallow foundations shall be designed to limit total settlement to no more than 3/4-inch. Differential settlements shall be no more than 1/2-inch between adjacent supports or L/1000 (where L is the distance between two supports in inches), whichever is less.

10.6.6.2 Deep Foundations

Where shallow foundations cannot be used due to presence of soft, compressible soils, deep foundations such as piling can be considered. Design of deep foundations shall be in accordance with AASHTO LRFD Design Specifications.

10.6.6.3 Miscellaneous At-Grade Structure Foundations

Design of foundations for miscellaneous structures shall be in accordance with the requirements above for shallow foundations, excepting that presumptive values may be used. These include, but are not limited to miscellaneous structures such as light standards, retaining walls less than

5 feet in height and are not supporting any structures, and other lightly loaded and uninhabited structures.

Cantilever signs and signals shall be supported on drilled shaft foundations. Design for cantilever signals and signs shall be performed in accordance with the AASHTO Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals (AASHTO 2001). Seismic issues related to foundation design such as downdrag and lateral spread due to liquefaction shall be addressed as stated in this chapter.

Foundation design for noise barriers shall be conducted in accordance with Caltrans Memo To Designer 22-1, Soundwall Design Criteria. Seismic issues related to foundation design such as downdrag and lateral spread due to liquefaction shall be addressed as stated in this chapter.

10.7 Retaining Walls and Trenches

The criteria set forth in this section govern the static load design of retaining walls and trenches (retaining walls with a continuous base slab between them). The design shall conform to the applicable requirements set forth in Article 11 of AASHTO LRFD BDS with Caltrans Amendments, FHWA's Earth Retaining Structures Reference Manual, and the sections specified in this chapter. For permanent surcharge loads, refer to Section 10.11.5. For design loads of the HST, refer to the *Structures* chapter.

Retaining walls can be classified as either a "fill wall" or a "cut wall." Acceptable fill walls include standard cantilever walls, mechanically stabilized earth walls, reinforced soil slope embankment, and modular gravity walls (gabions and crib walls). Acceptable cut walls include soil nail walls, cantilever soldier-pile walls, slurry walls, secant pile/tangent pile walls, and ground anchored walls (other than nail walls).

10.7.1 Design

Design of retaining walls shall consider the following conditions of external instability where applicable:

- Sliding in connection with a horizontal displacement of the structure
- Overturning or excessive settlement
- Failure of the structure base (allowable soil pressure exceeded)
- Overall stability behind and under the structure (soil shear failure)
- Liquefaction potential of the supporting ground

For geotechnical design, refer to Article 11 of AASHTO LRFD BDS with Caltrans Amendments.

Design of mechanically stabilized earth structures and reinforced soil slope embankments shall be in accordance with the LRFD version of FHWA's manual FHWA-NHI-10-024/25 "Design and

Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes", Volumes 1 and 2. Embedded metallic strip reinforcing elements shall not be used since they are potentially susceptible to stray current corrosion that may cause significant loss of reinforcement over the life of infrastructure supporting track.

10.7.2 Unacceptable Walls

Unacceptable retaining walls include mortar rubble gravity walls, timber or metal bin walls, "rockery" walls, and other wall types not specifically listed in Section 10.7.

10.7.3 Stability of Retaining Walls

Retaining walls, abutment walls, and basement walls shall be evaluated and designed for internal, external (sliding and overturning), and global stability. In addition to the static loads, the retaining walls shall be designed to resist the dynamic (seismic) earth pressure (ED), hydrodynamic force (WAD) and (water pressure), if submerged, under the seismic loading conditions.

Except for abutment walls where they shall be designed using the Service-1 Limit State loads, geotechnical designs for retaining walls and basement walls shall be performed in accordance with AASHTO LRFD BDS with Caltrans Amendments. Earth pressures used in design of the walls and abutments shall be selected consistent with the requirement that the wall/abutment movements shall not exceed tolerable displacement and settlement set forth in this chapter.

Retaining walls that are not restrained from rotation at the top, which are located where Peak Ground Acceleration (PGA) values (i.e., from MCE ground motion) are less than or equal to 0.30g, shall be designed for only active pressures, surcharge loads, and inertial forces of the wall itself; additional dynamic (seismic) earth pressures shall not be considered. For walls containing cohesionless material as backfill, seismic active pressures shall be estimated using the Mononobe-Okabe (M-O) method (Mononobe and Matsuo, 1929) only under the following conditions:

- The material behind the wall can be reasonably approximated as a uniform, cohesionless soil within a zone defined by a 3H:1V wedge from the heel of the wall
- The backfill is not saturated and in loose enough condition such that it can liquefy during shaking
- The combination of horizontal acceleration coefficient (K_h) and vertical acceleration coefficient (K_v) and backslope angle, *i,* do not exceed the friction angle of the soil behind the wall as specified by:

$$\phi \geq i + \arctan(K_h/(1-K_v))$$

For wall geometry or site conditions for which the M-O Method is not suitable, the Generalized Limit Equilibrium (GLE) Method shall be used to determine seismic active earth pressures.

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Horizontal seismic coefficient (K_h) shall be estimated using the Bray et al. (2010) method[1] assuming a wall movement of 1 inch. The earth pressures shall be separated into the incremental seismic pressures and the active earth pressures in the following manner:

$$\Delta K_{AE} = K_{AE} - K_A$$

Where:

ΔK_{AE} = Incremental seismic pressure coefficient

K_{AE} = Total seismic pressure coefficient

K_A = Active pressure coefficient

The incremental dynamic (seismic) earth pressure shall be taken as a triangular distribution with the resultant acting at 0.33H from the bottom (i.e., an upright rather than inverted triangle). This pressure shall be added to the active earth pressure for the design. For higher angles of sloping back fills where the M-O solution does not converge (see Figure 7.8 of NCHRP Report 611) methods presented in Chapter 7 of the NCHRP Report 611 shall be utilized. For backfill materials consisting of cohesive or cohesive and frictional (c-ϕ) material, methods presented in Chapter 7 of the NCHRP Report 611 shall be used.

For basement walls (or walls restrained against rotation) in locations where PGA values (for MCE ground motion) are less than or equal to 0.35g, walls shall be designed for only at-rest pressures, surcharge loads, and inertial forces from the wall itself, but additional seismic loads shall not be considered. For higher PGA values, the higher of the at-rest pressures or the active plus M-O pressures shall be used for the design. Seismic coefficient value (K_h) shall be estimated using Bray et al. (2010) assuming a wall movement of 1 inch.

The no-seismic-load options mentioned above shall be limited to internal and external seismic stability design of the retaining wall and to the condition that no liquefaction and severe strength loss in sensitive clays occur that can cause wall instability. If the wall is part of a bigger slope, overall seismic stability of the wall and slope combination shall still be evaluated.

10.7.4 Base Pressure

Soil bearing pressures shall be determined based on the applicable backfilled bearing materials. In order to minimize differential settlement and excessive outward tilting of walls, walls shall be proportioned so that the base pressure on soil under the footing is as nearly uniform (within 10 percent) as practical under the long term loading.

[1] Bray, J. D., Travasarou, T., and Zupan, J. (2010). “Seismic Displacement Design of Earth Retaining Structures.” *Proceedings, Earth Retention Conference 3*, Bellevue, Washington, August 1-4

10.7.5 Hydrostatic Pressure (Buoyancy)

Refer to the *Structures* chapter for design criteria for water loads (hydrostatic pressure) (buoyancy).

The use of tiedowns, tension piles, or other elements specifically designed to resist uplift forces shall be permitted. The use of augercast piles shall not be allowed as an anti-buoyancy hold down structure. The use of tension elements to resist buoyancy shall not compromise waterproofing and shall be designed to prohibit corrosion and be designed with the same design life as the rest of the structure.

10.7.6 Settlements and Horizontal Deformations

Retaining walls directly supporting HSTs shall be designed not to exceed settlement of 3/4-inch and horizontal deformation of 1/2-inch. To avoid long-term deflections in the track, track structures shall not be constructed until the majority of estimated retaining wall settlement has already occurred. Use of ground improvement methods may be required to expedite settlement, mitigate lateral deformations, as well as potential seismic hazards such as liquefaction and seismic instability.

10.7.7 Drainage

Adequate drainage behind retaining walls shall be included in the design and implemented during construction. An exception to this requirement is for trenches and underground structure walls where the top of trackway subgrade is below the groundwater table/flood level. These walls shall be designed to resist full hydrostatic pressures, both laterally and vertically (buoyancy).

10.7.8 Backfill

Backfill behind retaining walls shall be cohesionless and drained. Drainage systems shall be designed to completely drain the entire retained soil volume behind the retaining wall face. If drainage cannot be provided due to site constraints, the abutment or wall shall be designed for loads due to full hydrostatic pressure in addition to earth pressures.

The compaction of the backfill shall meet a minimum of 95 percent degree of compaction using the Modified Proctor Test in accordance with ASTM (D-1557) or AASHTO T180. Care shall be taken not to damage the walls during compaction using light compactor or hand-held tamper.

10.8 Embankments for HST Trackway

For roadway and site embankments, refer to the *Civil* chapter. For design loads, refer to the *Structures* chapter.

Embankments shall be engineered. Design of embankments shall focus on settlement of support ground and stability of embankment. Care shall be taken to avoid possible landslides within the embankment areas.

At each embankment, the following shall be evaluated:

- Slope stability
- Liquefaction potential of support ground
- Bearing capacity and plastic flow evaluation
- Construction of embankment shall not lead to reactivation of existing landslides or the formation of new ones
- Creep considerations
- Drainage considerations to avoid eroding the slope, scouring the toe, and clogging the water course
- Impact of Rayleigh-wave vibration induced by the high-speed train on the track-ground system composed of ballast/subballast or non-ballasted slab, embankment fill, and supporting subgrades
- Assessment of prepared subgrade, subballast/bearing base layers, and trackway; in particular (1) high dynamic effects on low embankments (less than 6.5 feet)/foundation soils and (2) critical speed issues of embankments over soft, compressible foundations with undrained shear strength less than 600 psf.

10.8.1 Slope Inclination

Fill – 2H:1V or flatter. Steeper slopes may be designed using geosynthetics (geogrids or geofabric) reinforcement to enhance the slope inclination.

Cut – 2H:1V or steeper if justified by slope stability analyses. Refer to Section 10.9.

10.8.2 Safety Factors

The stability of an embankment slope shall be determined using the Service-1 limit state. For the Service-1 static slope stability, the resistance factor is simply the inverse of the factor of safety (FOS). Table 10-4 shows the minimum required factors of safety for embankment slopes.

Table 10-4: Minimum Required Factors of Safety for Embankment Slopes

Loading Conditions	Factor of Safety
Normal (Permanent) (1)	≥1.50
Temporary (open less than 1 year)	≥1.30
Earthquake (OBE and MCE)	≥1.0 (2)

Notes:

(1) The factor of safety shall be in accordance with the requirements set forth by the local agencies.

(2) The stability of embankment slopes under earthquakes shall be analyzed by using the pseudo-static analysis, under the following conditions:

K_h depends on allowable slope deformation (Refer to Bray and Travasarou (2009) for estimation of K_h). Refer to Section 10.B.2.9.2 of *Appendix 10.B – Guidelines for Geotechnical Earthquake Engineering*.

$K_v = 0$

Where:

K_h = Horizontal seismic coefficient

K_v = Vertical seismic coefficient

10.8.3 Settlements

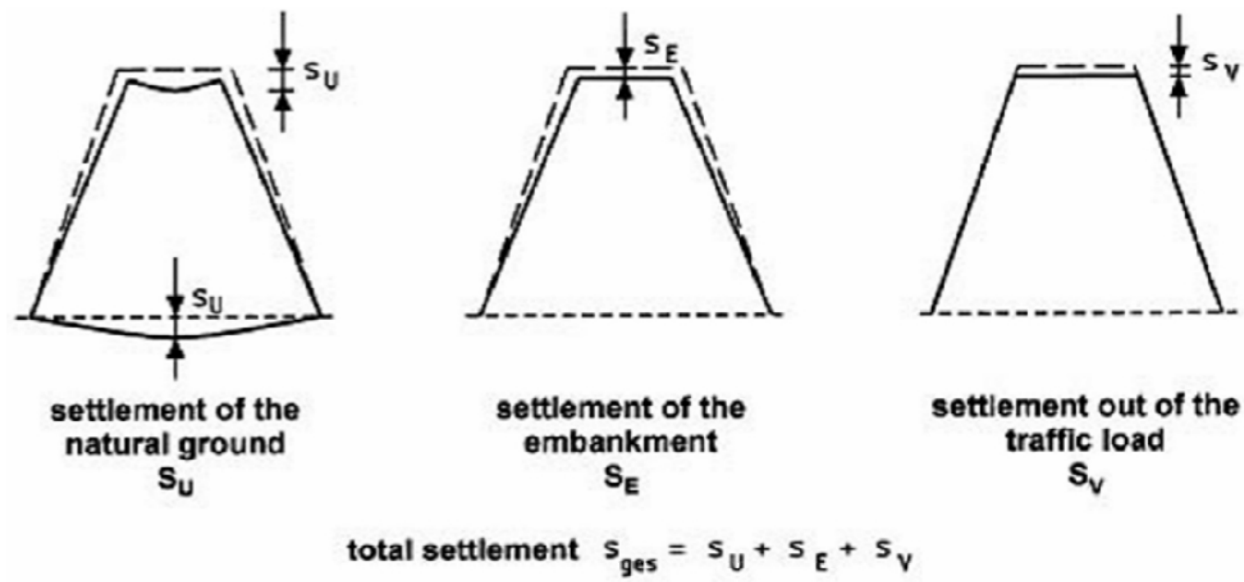
Once the embankments are designed to meet safe allowable bearing pressures and satisfy stability, settlements of the embankments during and after construction shall be evaluated. Settlement assessment shall be performed in the following critical areas:

- Approaches to bridge abutments
- Soft and organic layers beneath the embankment
- Subsiding areas

The vertical deformation ‘settlement’ of embankments (which also affects overlying trackbed structure) is a combination of the settlement movement of the foundation on which it is resting, plus settlement of the embankment fill, as shown in Figure 10-1. Conventional settlement analyses shall consider ‘immediate’, ‘consolidation’, and ‘secondary’ components of settlement against the requirements of CHSTP. For analysis of embankments, calculation procedures in the following references shall be used to assess soil settlement:

- Soil Slope and Embankment Design Manual, chapters 4 and 8, FHWA-NHI-05-123, 2005
- Soils and Foundations Reference Manual, chapter 7, FHWA-NHI- 06-088 Volume I, 2006

Figure 10-1: Settlements of Embankments



Notes:

Reference: Figure no. 21 of UIC-719R (2008)

Geotechnical evaluations for embankments and their foundations shall include the settlement contribution from surcharge/track load, high-speed train induced vibration, and additional loading and/or ground deformation due to earthquakes.

Once the embankments are designed based on safe bearing pressures and satisfying stability, the ‘residual’ settlement estimates and differential displacements between locations along the length of the embankments shall be evaluated to assess potential serviceability problems for the trackbed.

Residual settlement occurring after construction of the “permanent way” tracks shall be limited along general track segments as shown in Table 10-5.

Table 10-5: Maximum Residual Settlement Limits

Residual Settlement [1]	Non-Ballasted Track	Ballasted Track
Differential Settlement [2]	≤ 3/8 inch over 62 feet	≤ 3/4 inch over 62 feet
Uniform Settlement	≤ 5/8 inch	≤ 1-1/8 inch

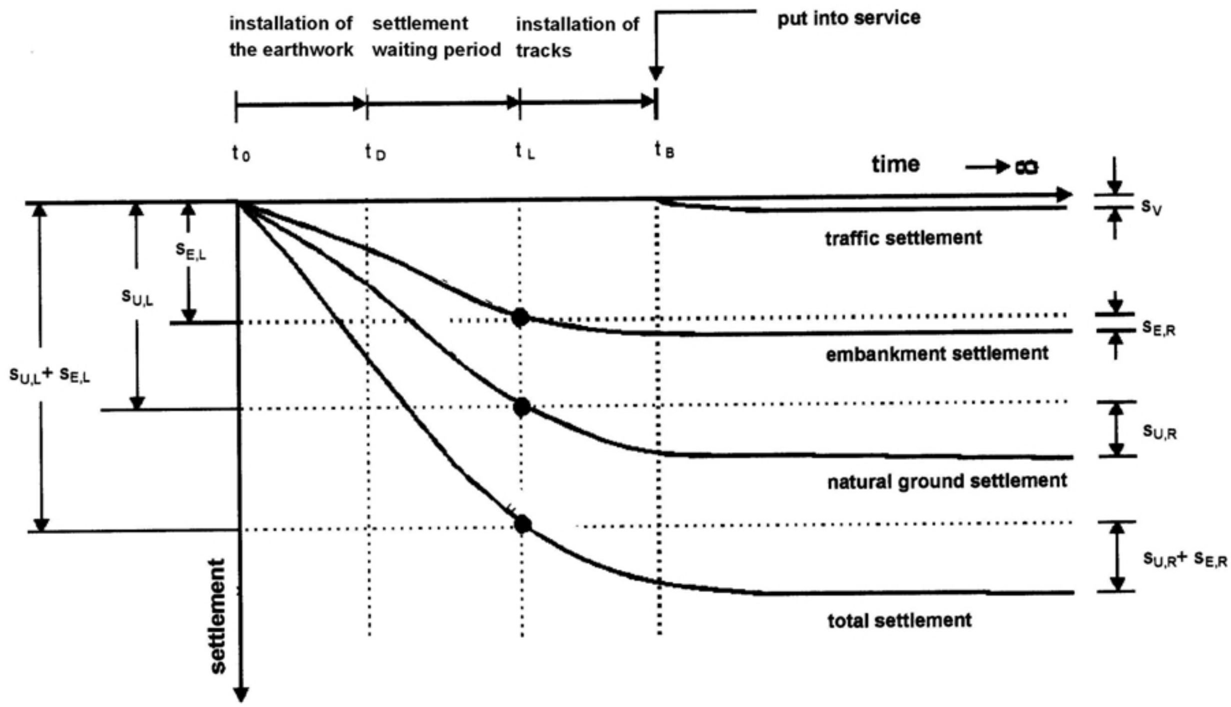
Notes:
(1) Embankment shall be instrumented and monitored for a period of at least 12 months following completion of the structure. The Geotechnical Designer shall demonstrate future compliance with the residual settlements in Table 10-5 by extrapolation from the monitored data.
(2) Differential settlement shall be measured along the track (surface profile uniformity) in the vertical plane of each rail at the mid-point of a 62-foot long chord.

Embankments shall be designed and constructed so as not to exceed the maximum residual settlement set forth in Table 10-5. "Residual" settlements occur after the monitoring period and completion of the embankments and shall be limited along the general track segments.

If the predicted differential displacements are excessive and exceed track profile tolerances, then embankment designs shall be modified and ground improvement designed if needed to act as a foundation system. Where predicted settlement movements and their duration are excessive, consideration shall be undertaken to change the design from an embankment to a viaduct or other structure.

Settlement of earth structures is time-dependent and will vary by segment, the time duration “waiting (leaving) period” shall be evaluated and established following initial fill embankment placement before releveling of subgrade. After this evaluation and establishment of the waiting period, subsequent construction of the overlying trackbed “permanent way” is allowed to take place. An illustration of various settlement parts related to time is shown in Figure 10-2. To meet CHSTP design and performance requirements, a settlement survey program shall be developed and then implemented during and after the construction phase to monitor settlement at the “acceptance check” timeframe after laying track, and then long term ‘residual’ settlement as part of the track maintenance program.

Figure 10-2: Different Settlement Parts by Time



Notes:

Reference: Figure no. 22 of UIC-719R (2008)

Commentary: Per UIC 719R section 2.10.2.2 - Elastic vertical displacement of earthworks under load is usually not a design criterion, as resistance of continuous supporting structure generally implies very low vertical displacement (typically 0.004 to 0.008 in (or 0.1 to 0.2 mm) on top of supporting structure). However design criteria may exist to limit elastic deformation to a percentage of deformation of track components to manage the global track stiffness.

10.8.3.1 Embankment Foundation Settlement Mitigation and Foundation Modification using Ground Improvement Methods

For track embankment segments or at-grade trackway features that do not meet settlement criteria or indicate stability problems, advanced mitigation measures such as pre-loading, over-excavation and replacement, or other ground improvement methods/measures shall be considered for geotechnical design. The selection of mitigation methods/measures shall follow the process described in detail in FHWA's Ground Improvement Reference Manuals Volumes I and II; FHWA-NHI-06-019/020 dated 2006.

A settlement monitoring program shall be developed and implemented during the construction phase for any mitigation method/measure selected. Interferometric Synthetic Aperture Radar (InSAR) techniques shall be considered as possible methods for large scale 'regional' monitoring in addition to traditional surveying and use of geotechnical instrumentation during and after construction.

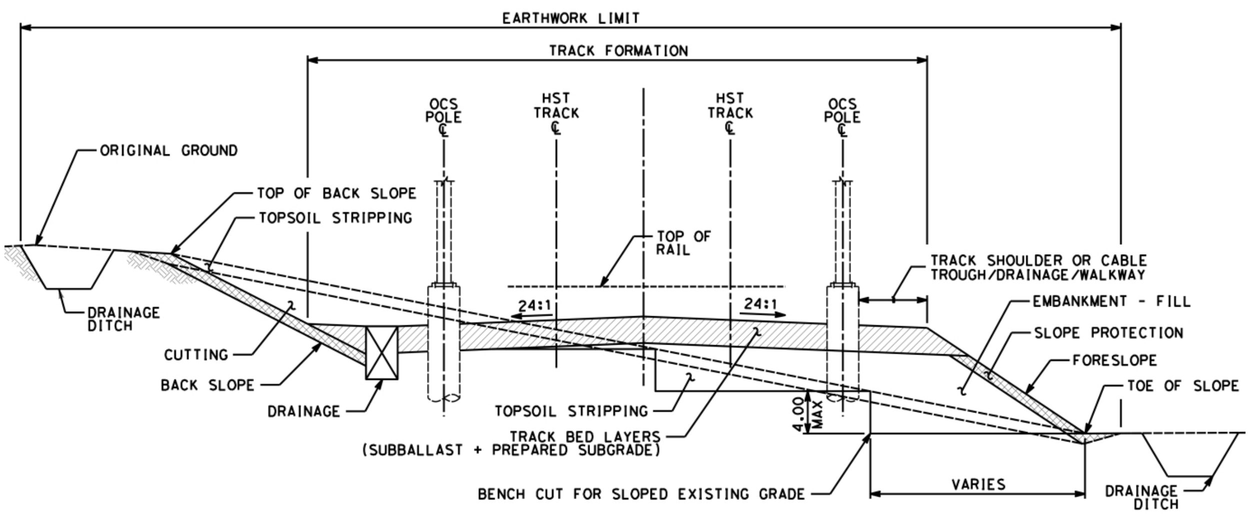
10.8.4 Benching of Slopes

For embankments higher than 30 feet (measured from existing ground surface to top of slope), design shall be include a mid-slope benches to mitigate surface erosion and to facilitate future access for maintenance reasons. Slope benches shall be at least 6 feet wide with a 4 to 6 percent slope towards the low end of the slope with a lined drainage channel. For embankments higher than 30 feet, slope benches shall be designed at every 25 to 30 feet in height connected to the surrounding ground surface for access.

At the top surface of the embankment, transverse cross-slope for drainage shall be 24:1 towards the outer edges of the embankment foreslopes (see Figure 10-3).

When an embankment is constructed next to an existing slope, the existing slope shall be benched in steps (typically 5 to 10 feet wide and no greater than 4 feet deep) to assure the fill embankment is keyed into the existing slope (see Figure 10-3). Drainage measures shall be placed on these benches to facilitate and convey groundwater to discharge outlets.

Figure 10-3: Typical Section Earthwork Cut/Fill



10.8.5 Particular Requirements

10.8.5.1 Foundation Support

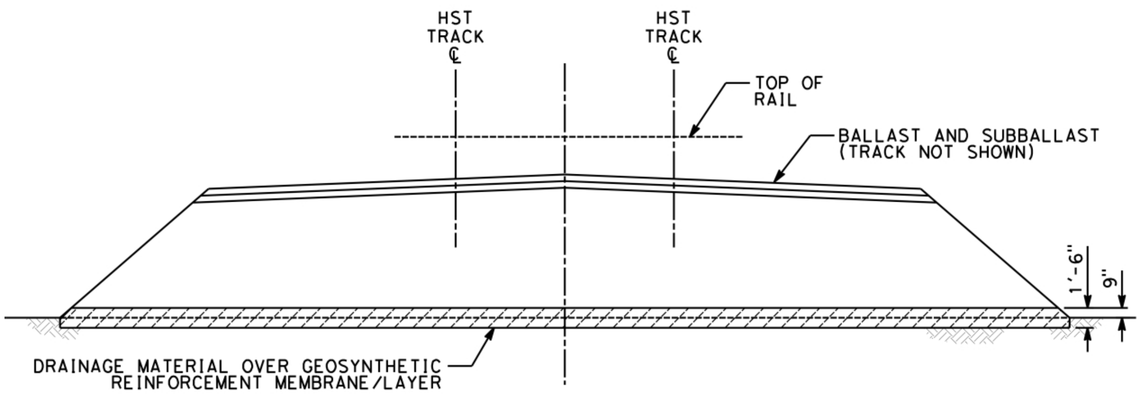
If the height of the embankment is less than or equal to 6.5 feet, as measured from the flat top of the subballast at the side edge of the embankment to the existing ground surface, and the foundation subgrades are loose and soft, compressible soils, they shall be removed and replaced with backfill and compacted to ensure settlement criteria.

For embankment heights greater than 6.5 feet over loose, soft, and compressible subgrade soils, the global stability and settlement induced by the embankment load shall be determined and ground improvement implemented, if necessary, to improve stability and achieve settlement criteria.

10.8.5.2 Embankments in Wet Conditions

In case an embankment is located in a wet area where the groundwater table is permanently or periodically at ground level, the embankment shall be constructed on a layer of drainage material as depicted on Figure 10-4. This material shall not swell or deteriorate when immersed in water. It shall be well graded with no more than 10 percent passing the No. 200 sieve. The grading of the drainage material shall be designed according to Sherard's filter criteria (Sherard et al., 1984). A layer of geosynthetic cloth shall be placed below the drainage material to provide a better support to the drainage material.

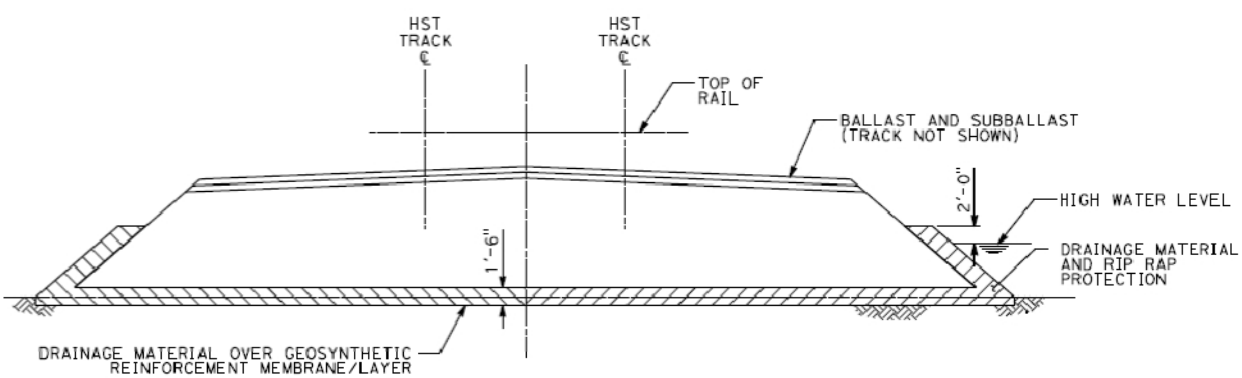
Figure 10-4: Earthwork Embankment in Wet Conditions



10.8.5.3 Embankment in Flood Plains

Where an embankment is located in a floodplain, the highest flood water level shall be determined from the 100-year flood. The embankment shall be, in addition to the drainage layer arrangement in Section 10.8.5.2, designed to protect the slopes within the highest water level with a layer of drainage layer and protection riprap as depicted on Figure 10-5. The drainage material shall be designed to comply with Sherard's filter criteria. This layer shall extend up to the highest flood water level plus 2 feet and be underlain by a layer of geosynthetic membrane.

Figure 10-5: Drainage Layer under Embankments in Floodplain / High Water



10.8.5.4 Embankments over Active Fault Locations

Where possible, embankments shall be located outside of active fault lines and founded on competent grounds. If this cannot be avoided, the embankments shall be designed with layers of geosynthetic cloth with drain rock or concrete mat at the bottom and containment earthworks wide enough to accommodate the potential rupture offsets and subsequent re-alignment.

10.8.5.5 Embankments on Potentially Liquefiable Soils/Compressible Soils

Where embankments are underlain by soft compressible soils or loose saturated soils that indicate high potential of liquefaction under OBE and MCE earthquakes, mitigation shall be required. The following soil improvement methods should be considered to mitigate soil liquefaction and increase the consistency of the foundation subgrade:

- Replacement
  - Excavate and replace with compacted fill
- Vibratory Densification
  - Vibro-compaction
  - Vibro-replacement stone columns (combination of vibration and displacement)
  - Deep dynamic compaction
- Displacement Densification/Reinforcement
  - Compaction grouting
  - Displacement piles
  - Vibro-replacement stone columns (combination of vibration and displacement)
  - Rammed aggregate piers (Replacement or Displacement type)
- Mixing/Solidification
  - Permeation Grouting
  - Deep soil mixing
  - Jet grouting
- Surcharge with wick drains (for soft compressible soils)
- Lime columns for soft compressive clays
- Drainage (only used in combination with other ground improvement methods listed above)
  - Passive or active dewatering systems
  - Pipe Pile Stone Columns (drainage in combination of vibration and displacement)

Ground improvement design shall be in accordance with FHWA Ground Improvements Reference Manual Volumes 1 and 2, FHWA-NHI-06-019 and FHWA-NHI-06-020.

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10.8.5.6 Rayleigh-Wave Induced Vibration by High-Speed Trains on Embankments and Structures

High-speed trains will produce compressive (P) waves, shear (S) waves, and Rayleigh (R) waves, of which Raleigh waves(moving parallel to the ground surface) are the primary source of vibrational energy. This vibrational energy could have a substantial destructive and fatiguing effect on the HST track-ground system composed of rails, embankments, and foundation subgrades. In addition, ground vibrations generated by high-speed trains are of great concern because of the possible damage they can cause to buildings or other structures near the track and the annoyance to the public living in the vicinity of the track. Particularly in soft-soil regions, where the wave speed is comparable to the speed of the trains, a strong increase of the vibration level can occur. The impact of the high-speed train-induced ground vibration on the track-ground system shall be evaluated and mitigated accordingly to avoid long term degradation of the HST track-ground system and all adjacent structures. For design purposes, the following shall be required:

- Vibration induced stability of the embankment shall be verified,
- Tracks shall be supported by well compacted ballast/subballast or slab track,
- Embankments supporting the track shall be adequately compacted, and
- Subgrade underlying the embankment shall be competent and firm, and if soft compressible soils are present, they shall be stabilized with ground treatment to increase its overall stiffness with undrained shear strength and E_{v2} exceeding 15 psi and 6,500 psi, respectively. E_{v2} is the subgrade stiffness determined from the 2nd loading of a plate load test according to ASTM_D1883-67.

In addition, an instrumentation program shall be devised to investigate the effect of the stabilization measures before and after the measures are conducted.

10.8.5.7 Embankment Prepared Subgrade

Material and thickness of the prepared subgrade for each track type (ballasted and non-ballasted) shall be as noted in the “Thickness of Prepared Subgrade” table of Figure 10-6. For non-ballasted track where the embankment height is low (less than 6.5 feet as measured from the flat top of the subballast at the side edge of the embankment to the existing ground surface), excavation below existing grade is not required to achieve a 6.5-foot thick prepared subgrade if it can be demonstrated that E_{v2} of the existing subgrade is ≥ 11,500 psi after the foundation soil is proof-rolled. In this case, the thickness of the prepared subgrade can be reduced to the available thickness, but it shall not be less than 14-inch thick and E_{v2} ≥ 11,500 psi shall be provided.

10.8.5.8 Transition of Embankments to Structures

Embankments adjacent to the aerial structure abutments, tunnel portals, cut-and-cover structures, and cut sections with an abrupt topographic change shall be designed to minimize the differential settlement and to provide a smooth transition in the structural stiffness between

different infrastructures. Provide a smooth transition by stiffening the subballast/bearing base layer and the approach fill with soil cement as depicted on Figures 10-6, 10-7, and 10-8.

Figure 10-6: Transition from Concrete Slab to Embankment

THICKNESS OF PREPARED SUBGRADE		
MATERIAL	TRACK TYPE	THICKNESS
WELL GRADED SOILS CONTAINING 5% TO 15% FINES	BALLASTED TRACK	14"
	NON-BALLASTED TRACK	6'-6"

GRADATION FOR PREPARED SUBGRADE MATERIAL	
GRAIN SIZE (mm)	PERCENTAGE PASSING [D=20 TO 125 (mm)]
P(2D)	100
P(DMAX)	100~99
P(D)	99~85
P(D/2)	84~55
P(D/5)	60~31
P(D/10)	49~23
P(D/20)	40~17
P(D/50)	30~11
P(D/100)	22~8
P(D/200)	16~6
P(D/500)	9~3
P(D/1000)	6~2

D = NOMINAL GRAIN SIZE
Dmax = 1.25D IF D ≥ 50 mm;
Dmax = 1.58D IF D < 50 mm

NOTES:

1. TRANSITIONS SHALL BE DESIGNED TO MINIMIZE THE DIFFERENTIAL SETTLEMENT AND TO PROVIDE A SMOOTH TRANSITION IN THE STRUCTURAL STIFFNESS BETWEEN DIFFERENT INFRASTRUCTURES.
2. EMBANKMENTS SHALL BE DESIGNED SPECIFICALLY TAKING INTO ACCOUNT THE CONSTRUCTION SEQUENCE AND THE GEOMETRICAL, GEOLOGICAL AND GEOTECHNICAL CONDITIONS OF THE SITE.
3. THE MINIMUM SUBBALLAST (SUPPORTING BALLASTED TRACK) THICKNESS SHALL BE 9".

LEGEND:

MPD MODIFIED PROCTOR DENSITY (AASHTO T180)

E_{v2} DEFORMATION MODULUS OF SECOND LOADING

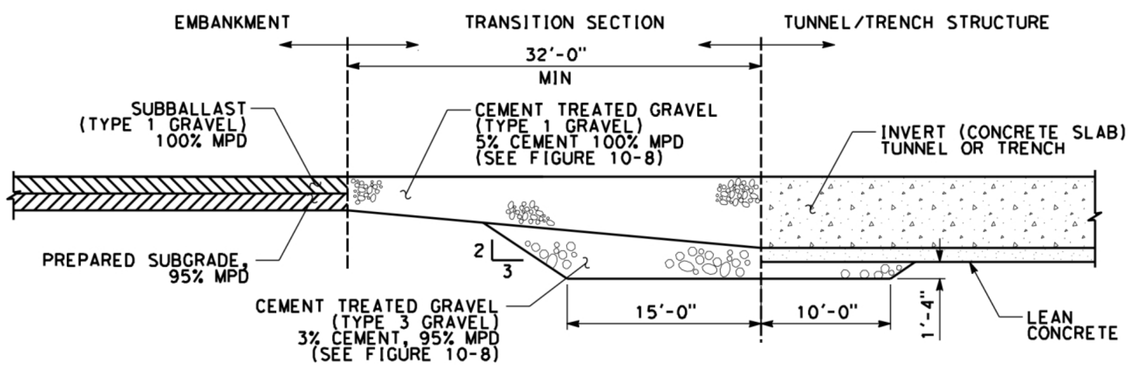

Figure 10-7: Transition from Cut to Embankment

THICKNESS OF PREPARED SUBGRADE		
MATERIAL	TRACK TYPE	THICKNESS
WELL GRADED SOILS CONTAINING 5% TO 15% FINES	BALLASTED TRACK	14"
	NON-BALLASTED TRACK	6'-6"

GRADATION FOR PREPARED SUBGRADE MATERIAL	
GRAIN SIZE (mm)	PERCENTAGE PASSING [D=20 TO 125 (mm)]
P(2D)	100
P(DMAX)	100~99
P(D)	99~85
P(D/2)	84~55
P(D/5)	60~31
P(D/10)	49~23
P(D/20)	40~17
P(D/50)	30~11
P(D/100)	22~8
P(D/200)	16~6
P(D/500)	9~3
P(D/1000)	6~2

D = NOMINAL GRAIN SIZE
Dmax = 1.25D IF D ≥ 50 mm;
Dmax = 1.58D IF D < 50 mm

NOTES:

1. TRANSITIONS SHALL BE DESIGNED TO MINIMIZE THE DIFFERENTIAL SETTLEMENT AND TO PROVIDE A SMOOTH TRANSITION IN THE STRUCTURAL STIFFNESS BETWEEN DIFFERENT INFRASTRUCTURES.
2. EMBANKMENTS SHALL BE DESIGNED SPECIFICALLY TAKING INTO ACCOUNT THE CONSTRUCTION SEQUENCE AND THE GEOMETRICAL, GEOLOGICAL AND GEOTECHNICAL CONDITIONS OF THE SITE.
3. THE MINIMUM SUBBALLAST THICKNESS SHALL BE 9".

LEGEND:

MPD MODIFIED PROCTOR DENSITY (AASHTO T180)

E_{v2} DEFORMATION MODULUS OF SECOND LOADING

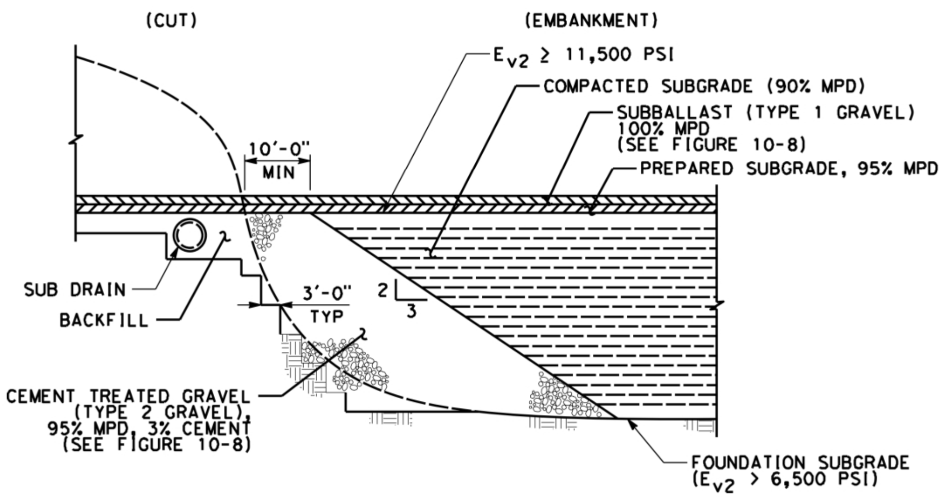

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Figure 10-8: Transition from Aerial Structure to Embankment

TYPE 1 GRAVEL NOTE:

CEMENT TREATED GRAVEL 0/31.5. COMPACTION SHALL BE GREATER THAN 100% OF MAX DRY DENSITY ACCORDING TO AASHTO T180 MPD. DEFORMATION MODULUS E_{v2} SHALL BE GREATER THAN 17,000 PSI.

TYPE 2 GRAVEL NOTE:

CEMENT TREATED GRAVEL 0/20. COMPACTION SHALL BE GREATER THAN 95% OF MAX DRY DENSITY ACCORDING TO AASHTO T180 MPD E_{v2} > 15,000 PSI.

TYPE 3 GRAVEL NOTE:

GRAVEL 0/60. COMPACTION SHALL BE GREATER THAN 95% OF MAX DRY DENSITY ACCORDING TO AASHTO T180 MPD. DEFORMATION MODULUS E_{v2} SHALL BE GREATER THAN 80 11,500 PSI.

TYPE 1 GRAVEL	
SIEVE	% PASSING
1.5 INCH	88~100
1.0 INCH	82~97
3/4 INCH	75~92
3/8 INCH	64~85
NO. 4	53~77
NO. 10	40~68
NO. 40	22~48
NO. 100	10~36
NO. 200	3~22

TYPE 2 GRAVEL	
SIEVE	% PASSING
3/4 INCH	83~100
3/8 INCH	53~83
NO. 4	36~65
NO. 10	23~49
NO. 40	12~31
NO. 100	7~19
NO. 200	4~12

TYPE 3 GRAVEL	
SIEVE	% PASSING
2.0 INCH	80~100
3/4 INCH	43~72
NO. 4	21~46
NO. 10	14~35
NO. 40	7~19
NO. 100	3~10
NO. 200	2~6

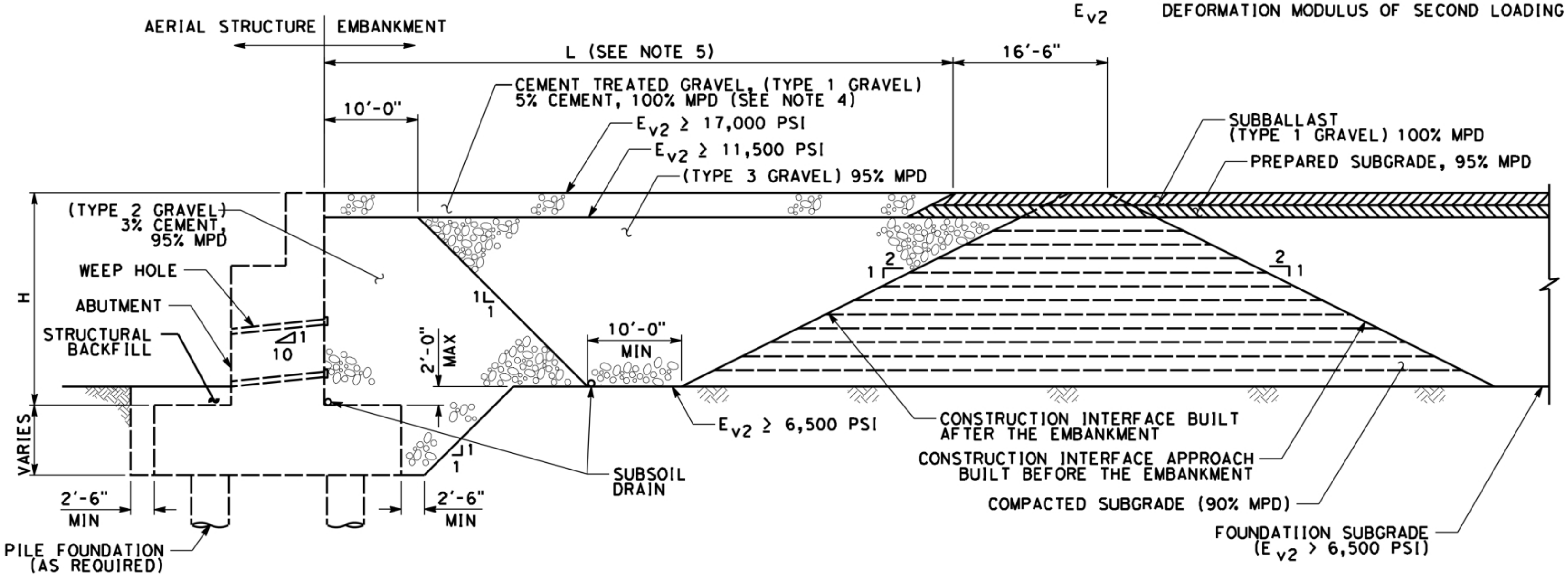
NOTES:

1. TRANSITIONS SHALL BE DESIGNED TO MINIMIZE THE DIFFERENTIAL SETTLEMENT AND TO PROVIDE A SMOOTH TRANSITION IN THE STRUCTURAL STIFFNESS BETWEEN DIFFERENT INFRASTRUCTURES.
2. EMBANKMENTS SHALL BE DESIGNED SPECIFICALLY TAKING INTO ACCOUNT THE CONSTRUCTION SEQUENCE AND THE GEOMETRICAL, GEOLOGICAL AND GEOTECHNICAL CONDITIONS OF THE SITE.
3. THE MINIMUM SUBBALLAST THICKNESS SHALL BE 9"
4. THE MINIMUM THICKNESS SHALL BE EQUAL TO THE COMBINED THICKNESS OF THE SUBBALLAST AND THE PREPARED SUBGRADE AND NO LESS THAN 1'-11".
5. LENGTH L, SHALL BE 4H OR 65'; WHICHEVER IS GREATER.
6. PREPARED SUBGRADE THICKNESS IS SHOWN ON FIGURES 10-6 AND 10-7.

LEGEND:

MPD — MODIFIED PROCTOR DENSITY (AASHTO T180)

E_{v2} — DEFORMATION MODULUS OF SECOND LOADING



10.8.5.9 Embankments in Cut Sections

Embankment design in cut sections shall include selection of appropriate earthworks for a given setting based on design constraints and potential conflicts, geotechnical subsurface investigations, and surface and groundwater issues. Figure 10-3 shows a typical embankment in a cut section.

10.8.5.10 Drainage (Surface and Subsurface)

Control of surface and ground water is essential to avoid surface erosion and potential slope instability. Provision shall be made in the design for an adequate system of surface and subsurface drainage and surface protection that incorporates sufficient capacity for the following:

- Design rainfall run-off to prevent long term erosion
- Build-up of groundwater that could result in slope instability

Notwithstanding the requirements of available relevant standards, consideration shall be given to the long term performance of the drainage and erosion control system for each embankment of fill under local conditions.

Where horizontal drains are to be used, a protective measure shall be devised to protect the drains from freeze/thaw. A long term maintenance program shall be developed by the Geotechnical Designer in order to safeguard the long term functionality of the horizontal drains.

Geotechnical design shall also include evaluation of temporary construction erosion control requirements on cut and fill slopes when integral to geotechnical design or performance. For example, the requirement to provide bench drainage during construction of slopes may be required to ensure construction phase stability.

10.8.6 Soil Materials Used for Embankments

For design purposes, evaluation of soil suitability for re-use within the body of embankments shall be based on the following guidelines:

Table 10-6: Soil Material Suitability for Engineered Fill in Embankments

Acceptable (1)	Unacceptable (2)
A-1-a	A-4 (CBR <10)
A-1-b	A-2-7
A-2-4	A-5
A-2-5	A-6
A-2-6	A-7-5
A-3	A-7-6
A-4 (CBR >10)	*

Notes:

Source: Per ASTM D3282 / AASHTO Subgrade Soil Group System

Refer to the *Trackwork* chapter and Standard Specifications for Trackbed layers of subballast and prepared subgrade.

* Rockfill is not acceptable for track embankment material.

(1) In addition to the AASHTO criteria, the maximum soil particle size is limited to 3 inches.

(2) Potential embankment fill source materials from groups A-2-7, A-5, A-6, and A-4 (with CBR <10) that can be shown by analysis and testing to meet performance requirements (including strength, stability, settlement/deformation, long-term durability, etc.) shall be submitted for consideration of acceptability on a case-by-case basis. This includes marginal soil types from these groups that can be 'modified' using soil amendments or additives such as cement, lime, hydraulic binders, etc., to be rendered suitable for use provided they meet performance requirements (described above) as demonstrated by analysis and testing programs including laboratory trial batching and field test sections.

Soil suitability evaluations shall also consider potentially detrimental properties as follows:

- Frost Susceptibility – soil types susceptible to frost, such as silt or clay, shall not be used for embankments in regions where cold conditions (below freezing temperatures) can occur in order to reduce the potential to cause unacceptable disturbances to track geometry upon freeze/thaw cycles.
- Corrosivity – soil suitability shall also consider corrosion potential.[4] Corrosive soils that are potentially detrimental to buried metal and/or concrete features (such as Overhead Contact System (OCS) poles, pipes/culverts, geogrid reinforcement, etc.) shall not be used.
- Slake Durability of Rock – based on the slake durability behavior in wetting and drying cycles.

10.9 Cut Slopes

Cut slopes include soil, Intermediate Geomaterials (IGM), and rock slopes, and shall be designed per the following sections. Sloped excavations during construction shall be designed

[4] Corrosion potential is the potential of a corroding surface in an electrolyte relative to a reference electrode measured under open-circuit conditions.

and constructed in compliance with local, state, and federal regulations, including but not limited to Occupational Safety and Health Administration (OSHA) and Cal-OSHA requirements.

10.9.1 Design of Cut Slopes

Design of cut slopes shall consider the following:

- Impact of slope instability to the HST facility operations and integrity (short term and long term)
- Slopes within existing pre-historic landslide areas
- Locations where liquefaction-related lateral spreading conditions are present
- Rock slopes with adversely oriented and kinematically unstable structural discontinuities such as joints, bedding planes, shear planes, gouges, and faulted zones

At each cut slope location, the following shall be evaluated:

- Locations where evidence of prior landsliding is present
- Slopes composed of quick, sensitive, and expansive clays

At each cut slope, the following shall be evaluated:

- Slope stability (static and seismic)
- Construction of the cut slope shall not lead to reactivation of existing landslides or the formation of new ones

For design of rock slopes, refer to *Appendix 10.C – Guidelines for Rock Slope Engineering*.

10.9.1.1 Design Requirements

Slope Inclination (Typical[5])

Soil cut – 3H:1V slope or steeper if justified by slope stability analyses

IGM cut – 2H:1V slope or steeper if substantiated by slope stability analyses

Rock cut – 1H:1V slope or steeper if justified by slope stability analyses

10.9.1.2 Safety Factors

For design criteria for stability of cut slopes , please refer to Section 10.8.2.

[5] The slope inclination design guidelines stated herein do not apply to the cut slopes in pre-historic landslide areas, prior landslide locations, and potential liquefaction related lateral spreading conditions, slopes composed of sensitive, quick, and expansive clays.

10.9.2 Drainage (Surface and Subsurface)

Drainage provisions and permanent erosion control facilities to limit erosion (including soil erosion and rock slope degradation) are required for design of cut slopes. Surface drainage shall be accomplished through the use of drainage ditches and berms located above the top of the cut, around the sides of the cut, and at the base of the cut. Erosion control for cut slopes shall be performed similar to those stated in Section 10.8.5.10 and Section 10.10.2. Impermeable coverings such as shotcreting (with or without ground reinforcements), stone-pitching, etc., shall be considered to protect rock slopes from degradation and deterioration due to weathering.

Subsurface drainage systems such as cut-off drains, horizontal drains, french drains, etc., shall be designed to permanently lower groundwater table to enhance overall stability of the slopes.

10.9.3 Slope Stability Mitigation Methods for Cut Slopes

Where the minimum required factors of safety cannot be achieved or the alignment cannot be relocated away from unstable slopes, the Geotechnical Designer shall design measures to enhance slope stability. Slope stability mitigation measures for cut slopes include the following:

- Soil Cuts
  - Flattening the slopes (if permitted by right-of-way) with vegetation cover
  - Buttressing the toe of the slopes
  - Stabilizing the slope with ground reinforcements such as soil nails and soil anchors with or without shotcrete
  - Covering the slope face with stone pitching, concrete, or shotcreting
  - Debris flow diversion walls
  - Retaining walls such as soldier pile walls, secant pile and tangent piles, gabion walls, etc.
  - Drainage and subdrainage measures
  - Ground improvements such as deep soil cement mixing or jet grouting
  - A combination of any of the above
- Rock Cuts
  - Rock scaling and dentition
  - Rock fall ditches
  - Rock fall retention meshes
  - Rock fall detention fences
  - Rock dowels and anchors

- Shotcreting
- A combination of any of the above

10.10 Existing Slopes

The Geotechnical Designer shall evaluate existing slopes for potential instability. At a minimum, the Geotechnical Designer shall mitigate unstable slopes to ensure that they will not pose a detrimental impact to the alignment.

10.10.1 Protection of Existing Slopes

The Geotechnical Designer shall be responsible for maintaining the stability of existing slopes during the course of construction. Slope instability that occurs during construction shall be repaired by the Geotechnical Designer at its own expense.

10.10.2 Drainage (Surface and Subsurface)

Erosion control and drainage measures shall be evaluated, considered and designed for existing slopes. Erosion of slopes presents a significant maintenance issue and overall stability concern. Rock and soil strata that are susceptible to erosion and/or freeze/thaw shall be mapped and delineated for existing and new fills and cuts. Slope protection measures shall be evaluated on site-specific conditions, such as surface and subsurface conditions, cut geometry, and susceptibility of erosion or deterioration. Each cut and fill slope that requires erosion control and drainage measures shall be evaluated for the following:

A. Reduction of water flow across slope

Where slope revegetation cannot be sufficiently established, reduce the quantity of water flowing over the slope from upland areas by means of drainage or interceptor ditches across the top of the slope and down the ends of the slope. At the base of the slope, water shall be directed to a discharge point. Coordinate discharge point drainage with existing facilities.

Drainage or interceptor ditches shall be lined or unlined and capable of carrying water generated from upland areas based on the 100-year storm. Lining materials shall be cast-in–place concrete, pre-cast concrete, reinforced shotcrete, or asphalt. Rock check dams to slow flows shall be designed and installed based on flow calculations.

B. Slope Revegetation

Where the slope can be made to support vegetation, local plantings shall be used to establish root systems to stabilize the surface of the slope and prevent deterioration of the slope. Design and provide systems of degradable woven blankets to temporarily hold plantings in place and minimize erosion until vegetation has established a stable root system.

C. Slope Armor

Where slopes will not support vegetation, slope cover/protection or permanent facing shall be used to protect the slope. Such measures as mattress-shaped steel wire mesh containers, gabions, articulated concrete blocks, fabric formed concrete, shotcrete, geosynthetic cells filled with gravel, and rip-rap (crushed stone) placed on a graded filter shall be evaluated, designed and installed. Stone sizes shall be designed based on design water flows.

D. Subsurface Water Control

Design of subsurface water drainage features shall be evaluated as water control measures. Design shall consider the use of horizontal drains, blanket drains, trench drains and geocomposites for both cut and fill slopes. Design shall consider outlet design and address long-term performance and maintenance requirements for the drainage system.

E. Springs and Water Seepage

Any springs and water seepage identified in the field shall be contained by means of drainage systems. Design shall consider long-term performance and maintenance requirements for the drainage system.

10.11 Cut-and-Cover Underground Structures

The cut-and-cover underground structures include subways, cross-passages, sump pump structures, stations, building basements, vaults, ventilation structures, and other structures of similar nature.

Underground structures shall include waterproofing protection, drainage systems and/or dewatering pumps as needed to prohibit water buildup in the underground structures.

10.11.1 Structural Systems

The structural system for cut-and-cover line structures shall be single and/or multi-cell reinforced concrete box structures, with walls and slabs acting one-way in the transverse direction to form a frame. Walls that provide temporary support of excavation shall not be used as part of the permanent structure. Expansion joints are required at locations of major change in structural sections such as from line structure to station. Construction joints shall have continuous reinforcing steel and non-metallic waterstops.

10.11.2 Hydrostatic Pressure (Buoyancy)

Refer to the *Structures* chapter for water loads (hydrostatic pressure) (buoyancy) for design criteria for buoyancy.

Refer to Section 10.7 on Retaining Walls and Trenches for types of systems to be allowed to resist buoyancy.

10.11.3 Temporary Support of Underground Structures

Equivalent static loads and deformations may be used to design temporary support systems such as wales, struts, and braces recognizing the short duration of these systems. These loads shall be provided by the Geotechnical Designer and shall be shown on the shoring design calculations and drawings.

In locations where adjacent buildings and their foundations create an interaction configuration in conjunction with temporary ground support structures that would significantly influence the seismic response of the adjacent buildings themselves, the combined group of temporary ground support and building structural configurations shall also be analyzed as a single permanent structure.

Refer to the *Structures* chapter for more structural detail.

10.11.4 Temporary Lateral Loading Conditions

Soil Pressures – The Geotechnical Designer shall have the responsibility of determining earth pressures of temporary earth support; however, the earth pressures shall not be less than those calculated assuming the active case. Pressures shall consider the impacts due to compaction. The temporary design of the wall shall not allow for overstressing of the wall.

Water Pressures – The temporary earth support system shall be designed to a construction term water level that is not lower than the existing groundwater level with consideration given to the potential of elevated groundwater conditions due to ground water re-injection activities.

Surcharge Loads – The earth support system shall include surcharge loads including, but not limited to traffic, construction material and equipment, and building loads.

Earthquake Loads – Refer to the *Structures* chapter.

Temporary Excavation Support Systems – Excavation and backfill sequence and strut installation and strut removal sequence shall be in accordance with the Designer of Record's design requirements.

Temporary earth support may remain in place or be removed following completion of the structure. Temporary earth support walls left in place shall be cut off at a depth not higher than 5 feet below grade or top of structure whichever is higher. Removal of temporary earth support walls shall be permitted. The settlement analysis shall indicate that removal will not cause settlement and lateral movement of adjacent structures, sidewalks, streets, and utilities. Tiebacks used to retain temporary support walls shall be de-tensioned prior to abandonment.

10.11.5 Permanent Lateral Loading Conditions

Soil Pressures – Permanent underground structures shall be designed for earth pressures as given in Section 10.7.3 on Stability of Retaining Walls. The at-rest pressures shall be used in the

design of cut-and-cover underground structures. In addition, hydrostatic pressures and seismic loadings shall also be included in the design of the underground structures.

Surcharge Loads – Loads from adjacent building foundations shall be used in the design of cut-and-cover underground structures unless these existing buildings are founded on piles or permanently underpinned at a depth below the zone of influence of the cut-and-cover structures. Horizontal distribution of loads from foundations of existing buildings shall be determined in accordance with AASHTO LRFD BDS with Caltrans Amendments, Article 3.11.6.

10.11.6 Deformation Limits for Support of Excavation Systems

Excavation support systems shall be designed to limit wall deformations that would otherwise lead to ground settlements, resulting in damage to the support systems or any superimposed structures and adjacent structures/utilities. Ground settlement and lateral deformation shall be limited to less than 3/4 inch and 1/2 inch, respectively. The Geotechnical Designer shall analyze the support of the excavation system taking into account the ground conditions, wall stiffness, requirements for wall bracing systems, global stability, and sequence of construction including timing of support installations to determine the deflection and settlements for open cut excavation methods.

10.11.7 Dewatering

Concrete placement of a cut-and-cover structure below a groundwater table shall be either by tremie concrete or placed in the dry. When placement in the dry method is chosen, a dewatering/groundwater control system shall be designed to permit placement of all structural elements in the dry. The bearing subgrade shall be kept dry and stable with no flowing, standing and/or piping of the groundwater permitted. Water levels within the limit of excavation shall be maintained a minimum of 5 feet below subgrade. Tremie seals, grouting, and other similar methods shall be permitted as part of dewatering/groundwater control methods.

Design and installation of a groundwater recharge system to protect nearby structures and utilities shall be performed to mitigate excessive ground settlements induced by dewatering. In addition, the dewatering system shall be designed so that the construction dewatering recharge system will not adversely impact existing fresh water aquifers.

10.12 Seismic Design

Seismic design requirements are also covered in the *Seismic* chapter and the *Structures* chapter. The geotechnically-focused elements of the seismic design criteria are presented in this section. Structures shall be designed to resist seismically induced forces and deformations due to ground motions resulting from an earthquake, and to meet the performance criteria specified in this document. Foundations shall be designed to address inertial loads from superstructures, liquefaction, lateral spread, and other seismic effects such that it will not experience damage

under the design earthquakes. Earth retaining structures shall be evaluated and designed for seismic stability internally and externally. Cut slopes in soil and rock, fill slopes, and embankments having impact on the operations of HSTs shall be evaluated for instability due to design seismic events and associated geologic hazards.

10.12.1 Design Earthquakes

For seismic design guidelines and performance requirements, refer to the *Seismic* chapter.

10.12.2 Liquefaction of Foundation Soils

Liquefaction may cause partial or total loss of shear strength of soils, thereby causing foundation instability, flow slides, lateral spreading and ground settlements. The Geotechnical Designer shall evaluate the possibility of ground failures caused by liquefaction, the potential impacts to foundations and structures, and mitigation measures to satisfy performance requirements.

Liquefaction-triggering evaluations shall be performed for sites that meet the following two criteria:

- The estimated maximum groundwater elevation at the site is within 75 feet of the existing ground surface or proposed finished grade, whichever is lower.
- The subsurface profile is characterized in the upper 75 feet as having soils that meet the compositional criteria of soils for liquefaction with a measured Standard Penetration Test (SPT) resistance, corrected for overburden pressure and hammer energy (N1)60-cs, less than 33 blows/ft., or a cone tip resistance qc1N-cs (defined as the normalized cone tip resistance with clean sand equivalence) of less than 185 ton per square feet, or a geologic unit is present at the site that has been observed to liquefy in past earthquakes.

Liquefaction-induced movement/settlement shall be estimated and compared with the allowable deformation values required in this chapter. The Geotechnical Designer shall develop mitigation measures accordingly to meet the allowable deformation values set forth in this chapter.

Guidelines for evaluation of soil liquefaction triggering potential are presented in *Appendix 10.B – Guidelines for Geotechnical Earthquake Engineering*.

Where potential for liquefaction exists under OBE and MCE earthquakes (as confirmed by liquefaction studies by the Geotechnical Designer) and its impact on foundations/structures is not acceptable, the following remedial measures shall be considered:

- Liquefiable soils shall be removed; or
- Soil improvement techniques shall be used (see Section 10.8.5.5); or

- Deep foundations such as piles or drilled shafts shall be used, and shall be designed to resist and accommodate the liquefaction-induced ground movements and force demands, taking into account the reduced soil properties as a result of liquefaction.

10.12.2.1 Compositional Criteria for Liquefaction Susceptibility for Soils

A. Sandy Soils

Sandy soils with few amounts of fines that meet the above-mentioned two criteria shall require liquefaction triggering evaluations.

B. Silty and Clayey Soils

Whether silty and clayey soils meet the criteria for liquefaction susceptibility shall be evaluated primarily using the criteria developed by Bray and Sancio (2006) and compared to results by analysis using the methods presented in Idriss and Boulanger (2008). The Modified Chinese Criteria for clayey soils in the Youd el al. (2001) method shall not be used.

For fine-grained soils that do not meet the above criteria for liquefaction, the effect of cyclic softening resulting from seismic shaking shall be evaluated and its impact on foundations/structures shall be analyzed and considered in the design.

Considering the range of criteria currently available in the literature, geotechnical engineers shall consider performing cyclic triaxial or simple shear laboratory tests on undisturbed soil samples to assess cyclic response for critical cases.

C. Gravels

Gravel layers bounded by lower permeability layers shall be considered potentially susceptible to liquefaction, and their liquefaction susceptibility shall be evaluated. A gravel layer that contains sufficient sand to reduce its permeability to a level near that of the sand, even if not bounded by lower permeability layers, shall be considered susceptible to liquefaction and its liquefaction potential shall be evaluated as such.

10.12.3 Underground Structures

Seismic design of underground structures shall be based primarily on the ground deformation approach specified herein. During earthquakes, underground structures move together with the surrounding soil/rock mass. The structures shall therefore be designed to accommodate the deformations imposed by the ground, taking into consideration the soil-structure interaction effect.

Seismic effects on underground structures take the form of deformations that in general cannot be changed significantly by stiffening the structures. The structures shall instead be designed and detailed to withstand the imposed deformations without losing the capacity to carry applied loads and to meet the performance goals of the structures. Shear capacity degradation and compressive strains shall be evaluated. If necessary, additional confinement reinforcement shall be added to increase ductility and shear capacity.

Underground tunnel structures undergo three primary modes of deformation during seismic shaking: ovaling/racking, axial, and curvature deformations. The ovaling/racking deformation is caused primarily by seismic waves propagating perpendicular to the tunnel longitudinal axis. Vertically propagating shear waves are generally considered the most critical type of waves for this mode of deformation (Figure 10-9). The axial and curvature deformations are induced by components of seismic waves that propagate along the longitudinal axis (Figure 10-10).

Figure 10-9: Tunnel Transverse Ovaling and Racking Response to Vertically Propagating Shear Waves

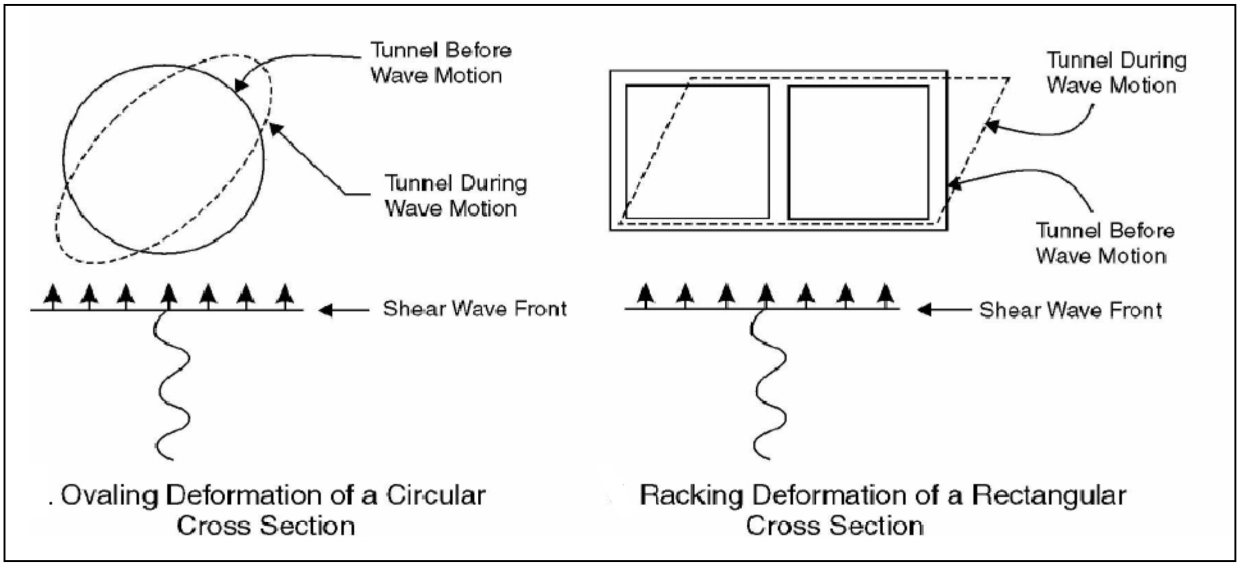
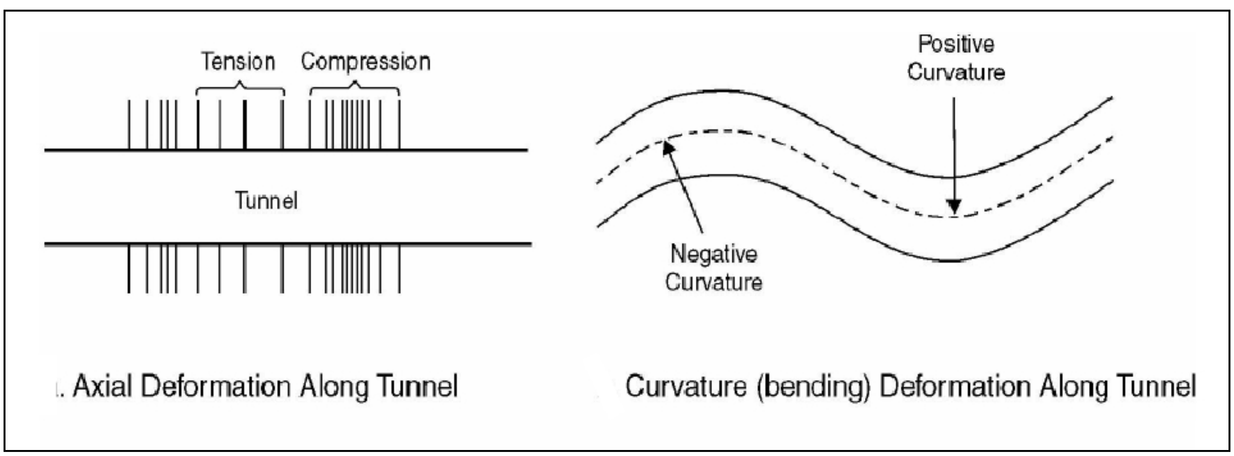


Figure 10-10: Tunnel Longitudinal Axial and Curvature Response to Traveling Waves



10.12.4 Effect of Ground Deformation

10.12.4.1 Transverse Ovaling Deformations

For bored circular tunnels, using either the precast concrete segmental lining or cast-in-place concrete lining, there are two general approaches to determining the effects of seismic ovaling deformation.

The first approach is based on closed form solution that accounts for soil-structure interaction effect. The closed form solution is based on the following assumptions: (1) the tunnel is of completely circular shape (without decks or walls inside) with uniform lining section, (2) surrounding soil is uniform, and (3) there is no interaction effect from adjacent tunnels or other structures.

The second approach is a numerical modeling approach that relies on mathematical models of the structures (including adjacent structures if relevant) to account for structural properties, varying soil stratigraphy and properties, loadings and deformations more rigorously. These structural models are generally run on computers with specialized software. If the actual soil-structure systems encountered in the field are more complex than the assumed conditions described above for the closed form solution approach which could lead to unreliable results, then the numerical modeling approach shall be adopted.

Refer to FHWA-NHI-09-010 Report, "Technical Manual for Design and Construction of Road Tunnels", Chapter 13 for general guidelines on transverse ovaling analysis for bored tunnels.

10.12.4.2 Transverse Racking Deformations

For box type underground structures such as cut-and-cover tunnels and stations, and mined station sections that behave in similar manner as a rectangular structure during earthquake shaking, seismic design of the transverse cross section of the structure shall consider two loading components:

- The racking deformations due to the vertically propagating shear waves, which are similar to the ovaling deformations of a circular tunnel lining (see Figure 10-9).
- Inertia forces due to vertical seismic motions.

There are two general approaches to determining the effects of seismic racking deformations:

The first approach is based on semi-closed form solution that has been calibrated with a series of numerical analyses for a number of soil-structure configurations. The semi-closed form solution is based on the following assumptions: (1) the tunnel is of rectangular shape, (2) surrounding soil is reasonably uniform, and (3) there is no interaction effect from adjacent tunnels or other structures.

The second approach is a numerical modeling approach that relies on mathematical models of the structures (including adjacent structures if relevant) to account for structural properties, varying soil stratigraphy and properties, loadings and deformations more rigorously. These

structural models are generally run on computers with specialized software. If the actual soil-structure systems encountered in the field are more complex than the assumed conditions described above for the semi-closed form solution approach leading to unreliable results, then the numerical modeling approach shall be adopted.

Refer to FHWA-NHI-09-010 Report, “Technical Manual for Design and Construction of Road Tunnels”, Chapter 13 for general guidelines on transverse racking analysis for box type structures.

10.12.4.3 Longitudinal Axial/Curvature Deformations

The evaluation procedures for the longitudinal response (due to axial/curvature deformations) of tunnel structures shall be based on the procedures outlined in Section 13.5.2 of the FHWA-NHI-09-010 Report, “Technical Manual for Design and Construction of Road Tunnels”. The Free-Field Deformation procedure in section 13.5.2.1 of the Road Tunnel Manual may be used to determine the strains related to axial and longitudinal deformation of the tunnel under seismic ground motions. Supplement the analysis with Numerical Modeling Approaches similar to those in Section 13.5.2.3 of the Technical Manual where there are abrupt changes in structural stiffness or geological properties.

For the Free-Field Deformation analysis, the combined axial and bending strains shall be calculated from the P-Waves (primary waves), S-Waves (shear waves), and R-Waves (Rayleigh waves) using the formulae given in Section 13.5.2.1 of the Technical Manual. The parameters associated with each class of wave are to be developed and provided by the Geotechnical Engineer/Seismologist.

Numerical modeling approach shall be used to investigate the effects of abrupt changes in structural stiffness or geological properties. Structural stiffness change locations can include the tunnel breakouts at the portals; where egress and ventilation shafts may join the tunnel; and other local hard spots. Geological changes requiring numerical modeling include area of abrupt change in soil stiffness along the alignment. These include the interfaces between liquefiable and non-liquefiable soils and the interfaces between soft soil and rock.

The effect of spatial variations of ground motions on long structures resulting from the effects of wave passage and local soil overburden shall be considered. The wave-passage effect results from different arrivals of seismic waves at different parts of the structure. The wave-passage effect can be accounted for by assuming a time lag of the ground-motion time histories between any two locations along the tunnel alignment. This time lag can be estimated by dividing the distance between the two locations by the horizontal wave travelling velocity (in the ground) VH = 2 km/sec along the tunnel alignment.

The effect of local soil overburden is specified in Section 10.12.4.4.

10.12.4.4 Site Response Analysis

Variations of local site conditions at different locations along the proposed tunnel alignment will have a major effect on the seismic response of the tunnel structures. The requirements and guidelines for evaluating the local site response effect on design ground motions are defined below.

Site response analyses shall be based on numerical modeling of the soil layering configuration, using site-specific soil properties along the tunnel alignment.

Several analysis methods are available for evaluating the effect of local soil conditions on ground response during earthquakes. The equivalent-linear one-dimensional total stress method shall be used. The non-linear one-dimensional total and effective stress method, the two-and three-dimensional equivalent-linear total stress methods, and the two- and three-dimensional non-linear total and effective stress methods shall also be used.

The one-dimensional site response analysis described above can be used for developing ground displacement profile for the evaluation the ovaling/racking effects on the seismic behavior of a tunnel's transverse section

To evaluate the tunnel's seismic performance in the longitudinal direction, the effect of subsurface variability in soil conditions along the tunnel alignment must be taken into consideration. When the soil/rock strata are highly variable and not horizontally layered, response analysis shall be performed with two-dimensional or three-dimensional modeling techniques.

For any numerical programs to be used (e.g., by finite element or finite difference methods), the Geotechnical Designer shall, prior to final design of any structural elements, verify the accuracy of such programs by a written report and with calculations that explain the theory, the input values, and the results.

10.12.5 Soil-Structure Interaction for Bridges and Aerial Structures

For bridges and aerial structures, the following primary soil-structure interaction effects shall be considered:

- The influence of foundation stiffness on structural response.
- The inertial structural loads imparted to the foundation system – termed as the inertial effect.
- The ground displacement loads imparted to the foundation system (resulting from both free-field soil displacement and ground-failure conditions such as lateral spreading or permanent seismically-induced embankment/slope movements if applicable) – termed as the kinematic effect.

The soil-foundation-structure interaction problem can be solved using either a coupled or uncoupled analysis. The coupled analysis examines the behavior of the entire soil-foundation-

structure system simultaneously in a single, complex model, in which non-linear soil behavior is described by a continuum model and/or non-linear soil springs (e.g., p-y, t-z, and q-z). In the uncoupled analysis, the effect of foundation stiffness on structural response is examined by replacing the foundation in the structural model with a set of spring (or stiffness matrix).

At a minimum, the soil-foundation-structure interaction effects shall be considered using the uncoupled approach using the stiffness matrix approach. In the event that a more detailed representation of the complex interactions between the superstructure, foundation and the surrounding soil is required, a fully coupled analysis shall be conducted.

10.12.5.1 Pile/Drilled Shaft Design Subject to Ground Displacements

Ground displacement loading can be divided into two categories: (1) free-field ground displacement and (2) displacement due to unstable ground such as liquefaction induced lateral spread or unstable embankments/slopes. Ground displacements impose forces acting along the length of the piles and pile cap and therefore shall be considered in the design. For the free-field ground displacements, the resulting forces can be estimated by imposing the estimated free-field ground displacement profile on the pile through p-y springs. Proper selection of the non-linear p-y properties of the surrounding soil is crucial for the design. The displacement profile can be estimated from a site response analysis. In competent sites, the free-field ground displacements generally do not govern the pile design because the curvature of the ground displacement is small. This effect, however, has to be considered for piles in soft soils and for sudden changes in soil stiffness with depth. The effect is particularly significant for large diameter piles or drilled caissons in soft soils.

Similarly, seismic soil instability resulting from geotechnical seismic hazards can produce large soil movements adversely affecting the performance of deep foundations. The p-y procedure described above is also applicable for this case. The ground displacements resulting from unstable ground require detailed analysis using site-specific data and shall be provided by the Geotechnical Designer.

The overall evaluation procedure for pile design in liquefied soil deposits would essentially be the same as that described above. However, the choice of p-y characteristics must properly consider liquefaction effects of the soils.

Computer program LPILE has the ability to impose a soil displacement profile against the pile by adjusting the location of the base of the soil springs (p-y). For calculation of loads and deformation demands on bridge foundations and abutment resulting from liquefaction induced spreading ground, refer to Caltrans Guidelines on Foundation Loading and Deformation Due to Liquefaction Induced Lateral Spreading (2011).

10.12.5.2 Effective Support Motions

Due to the complex interaction between soil, pile, and structures, the effective support motions (i.e., the near field ground motions) at the foundation/structure interface differ from those in the free field. For regular shallow footings and flexible pile-supported footings (relative to the

surrounding ground), using free-field motions as the support motions in the structure response analysis is reasonable. For very large and stiff foundations, such as large gravity caissons, very stiff battered pile groups, or large diameter drilled shaft foundations, the effective support motions at the foundation/structure interface may differ considerably from the free-field motions. When this situation occurs, a more refined analysis taking into account the presence of the foundation and the soil-pile/shaft kinematic interaction effect shall be performed to derive the effective support motions.

10.13 Formation Supporting Track Structures

Formation, defined as layers comprising subballast, prepared subgrade/subgrade, and earth fill, provides the base for track structure which is composed of rail track and ballast. The formation shall be designed to be safe against shear failure, and accumulated/plastic deformations under repetitive axle loads of the trains. The subballast and prepared subgrade/subgrade provide support to the track structure and bear additional stresses due to static and dynamic effects of moving wheel loads. The load is transmitted through the subballast, prepared subgrade/subgrade, and earth fill to foundation soils.

The ballast under the rail track serves as a stress disperser. Below the ballast is the subballast overlying the prepared subgrade/subgrade. This subballast layer (also referred to as the blanket layer in the UIC standards) shall be of adequate thickness to reduce the induced stresses to an acceptable level at the top of prepared subgrade/subgrade to avoid shear failure. The subballast shall have adequate strength under dynamic loads and vibrations, high resilient modulus, reasonable plastic strain accumulation characteristics under repeated wheel loads, etc. Therefore, the material shall be permeable enough to avoid any positive pore pressure build-up under repeated load. It shall consist of durable particles and should not be sensitive to moisture content. In addition, it shall resist break-down and abrasion from cyclic stresses produced by the train repetitive loading.

- Subballast – The subballast shall conform to the following design requirements:
  - It shall be coarse, granular, and well graded as per Standard Specifications.
  - Gap-graded material shall not be permitted.
  - It shall meet the minimum Resistance (R-value), Sand Equivalent and Durability Index requirements set forth in Standard Specifications.

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- Subgrade – Below the subballast is the subgrade layer, which in its most complete form, shall consist of a sandy gravel layer with gradation sizes per Standard Specifications. The upper part of the subgrade shall be formed into a prepared subgrade layer, which normally has a cross slope. This layer is made of imported or treated material depending of the quality of the upper part of the embankment or the bottom of the cut. It shall have a gradation as specified in Figure 10-6. Its deformation modulus, E_{v2}, from the 2nd loading in the plate load test shall not be less than 11,500 psi.
- Earth Fill – Underlying the subgrade is the fill (embankment fill/retaining structure backfill) on top of the existing foundation soils. This earth fill shall be designed against slope failure and settlement/deformation as provided earlier in this chapter.

10.13.1 Determination of the Thickness of the Trackbed Layers

Trackbed layers are composed of ballast and subballast which are placed on top of the prepared subgrade/subgrade. The dimensioning of trackbed layers shall take into account both the following:

- Desirable bearing capacity
- Problems of frost penetration

The total thickness (ballast layer plus sub-ballast layer) varies according to the following:

- Bearing capacity of the prepared subgrade
- Level of frost protection required
- Type of tie and the tie spacing
- Traffic characteristics (tonnage supported, axle-load and speed)

The thickness of the ballast varies depending on the train types, sleeper types, or whether non-ballasted tracks are used. The minimum thickness of subballast shall be 9 inches. For the prepared subgrade, a minimum thickness of 14 inches is required for ballasted tracks, whereas, a minimum thickness of 6 feet-6 inches of prepared subgrade is required for support of non-ballasted tracks unless otherwise stated in Section 10.8.5.7.

10.13.2 Design of Formation

Knowledge of cumulative plastic deformation for foundation soils under repeated loading is essential for the proper design of HST tracks. Excessive foundation soil plastic deformation will produce high maintenance costs and unwanted ride quality.

Design methods of formation, particularly for subballast thickness, are used in different railway systems. They are based on different properties of soil used in embankment construction which governs the behavior of the soil (viz. percentage of fines less than 75 microns) present in the soil, CBR value of the soil, undrained shear strength of the soil, etc. Methods such as the Association

of American Railroads (AAR) method (Li and Selig, 1998) may be used for design of the formation.

10.13.2.1 Rail Deflections

Rail deflections as a result of dynamic amplification due to high-speed trains shall be considered. These deflections are a function of (1) axle load of the train, (2) thickness of the embankment fill, (3) elastic properties of the sub-soil/foundation subgrade and the damping in the system, (4) train speed, and (5) both upward and downward rail deflections during the train passages. At certain speed of the train, “resonance” phenomena may cause rail deflections that are far larger than the static values.

Rail deflections induced by high-speed trains as a result of the dynamic amplification shall not exceed 1/8-inch and 1/2-inch for non-ballasted and ballasted trackways, respectively. Deformation analyses shall be performed to verify the rail deflections are within the required limits. If such limit cannot be achieved, consideration shall be given to increasing the thickness/stiffness of the prepared subgrade, subballast/bearing base layer and/or stabilizing the foundation subgrade.

10.13.2.2 Existing Embankments/Retaining Structures over Soft Grounds

In addition to checking against shear/bearing failure, design of high-speed train track formation over existing embankments underlain by soft ground shall be performed to evaluate the structural integrity of the formation supporting the trackways. The velocity of a high-speed train may approach or exceed the characteristic wave velocity of the dynamic system comprising the underlying soft ground, the formation, and the moving load. As the train’s velocity reaches some “critical velocity”, large deformations may occur. These motions could be dangerous for the train and the integrity of the track structure, and potentially costly in terms of track maintenance and performance. It is therefore vital to design the embankments which provide a dynamic stiffness that will limit track deflections to acceptable levels (see Section 10.8.3.1).

Analytical methods are used to model train-induced dynamic motion. Of these methods, the Winkler model may be used as it is a very prevalent and simple numerical model. In the Winkler mode, the embankment/rail/foundation material structure is simplified as a beam on an elastic or visco-elastic foundation, represented by a series of discrete springs and dashpots. The solution of the model may be used to calculate the critical velocity (V_{cr}) (Kenny, 1954) which is equal to:

$$V_{cr} = \sqrt[4]{\frac{4kEI}{\rho^2}}$$

Where:

k = Spring constant per unit length of the beam

E = Modulus of elasticity of beam

I = Moment of inertia of beam

ρ = Mass per unit length of beam

For design, the critical velocity of the embankments/retaining structures shall exceed 1.7 that of the design speed of the train.

10.13.2.3 Drainage of Formation

Water contained in the formation layers cause detrimental conditions in the track. Therefore, it is necessary to contain and reduce water content in the formation layers by the following measures:

- Removal of vegetation growth on surface
- Cleaning ballast bed and establishing cross fall slope at top of formation, subballast, and prepared subgrade/subgrade layers
- Provision of longitudinal drains and drainage outfall facilities
- Arrangement of lateral side drainage facilities

Appendix 10.A: Guidelines for Geotechnical Investigations

10.A.1 Purpose

These guidelines represent a preferred, but not necessarily the only actions required for the development of additional geotechnical investigations. These guidelines convey a minimum standard of care in performing geotechnical investigations and are not intended as prescribed site investigation criteria or checklists.

10.A.2 Geotechnical Investigation Guidelines

Geotechnical investigations are to be performed by a Geotechnical Designer in collaboration with an engineering geologist, both of which are licensed in the State of California. The level of geotechnical investigation performed shall consider the engineering needs and amount of information necessary to achieve performance criteria, complete the design, and mitigate construction risks. Guidelines for advancing the geotechnical investigations are described in the following sections.

The Geotechnical Designer/engineering geologist shall be required to present the investigation results in a Geotechnical Data Report (GDR) document that contains the factual information/ data gathered during the geotechnical investigations. The GDR shall minimally contain the following information:

- Summarize and reference to separate geologic hazards report
- Description and discussion of the site exploration program
- Logs of borings, trenches, and other site investigations
- Description and discussion of field and laboratory test programs
- Results of field and laboratory testing

The high cost component of geotechnical investigations is borehole drilling; therefore, planning of the geotechnical investigations shall maximize the use of existing geologic and subsurface data, and optimize the use of geophysical testing and Cone Penetration Tests (CPTs) where warranted in order to minimize the amount and cost of drilling required and still achieve a level of knowledge commensurate with good engineering practice and judicious judgment for similar locations and applications. Geotechnical investigations shall not begin until project specific information is gathered as set forth in the following sections.

10.A.2.1 Standards and Key Geotechnical Investigation Reference Documents

The ASTM test methods, Caltrans Manual, and FHWA manuals are considered the most comprehensive and applicable guideline documents for geotechnical investigation of the CHSTP as well as federal transportation projects. Chapter 6 of the 2008 FHWA Project

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Development and Design Manual (PDDM) provides an overview of practice for geotechnical work and direction for understanding policies and standards for geotechnical work performed by the Federal Lands Highway (FLH). The PDDM also provides a portal to technical information and presents a high-level source of technical guidance with regard to what needs to be accomplished. The corresponding 2007 FHWA Geotechnical Technical Guidance Manual (GTGM) provides guidance as to how the work shall be done. The GTGM also provides guidance for activities where standards and standard practices do not exist and provides access to and guidance for the use of new technologies. Chapter 3 of FHWA-NHI-09-010 presents good geotechnical investigation techniques and parameters for planning, design, and construction of road tunnels. For soil and rock logging, classifications, and presentation, refer to 2010 Caltrans Soil and Rock Classification, Classification, and Presentation Manual.

10.A.2.2 Geotechnical Investigation Goals

The goals of geotechnical investigations project are to:

1. Perform additional subsurface investigations to supplement existing geotechnical data for design of structural elements including bridges, retaining walls, at-grade structures, cut-and-cover tunnels, large culverts, mast arm supports (OCS, signals), wayside equipment, and signs along the proposed alignment.

2. Identify the distribution of soil and rock types within the project limits and assess how the material properties will affect the final design and construction of the project elements.

3. Define the groundwater and surface water regimes, especially, the depth, and seasonal and spatial variability of groundwater or surface water within the project limits. The locations of confined water-bearing zones, artesian pressures, and seasonal or tidal variations shall also be identified.

4. Identify and characterize any geologic hazards that may be present within or adjacent to the project limits (e.g., faults, landslides, rockfall, debris flows, liquefaction, soft ground or otherwise unstable soils, seismic hazards). These items are vital pieces of the overall geotechnical exploration process, and the investigators must ensure that these elements are addressed.

5. Assess surface hydrological features (infiltration or detention facilities) that are required for the project, as well as determine pond slope angle and infiltration rates to enable estimation of the size and number of those facilities.

6. Identify suitability of onsite materials as fill and/or the suitability of nearby materials sources.

7. For structures including bridges and cut-and-cover tunnels, large culverts, signs, signals, walls, or similar structures, provide adequate subsurface information for final design and construction.

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8. For tunnels, trenchless technology, or ground improvement, provide adequate information to determine the viability of construction methods and potential impacts to adjacent facilities.

9. For landslides, rockfall areas, and debris flows, provide adequate information to determine stabilization or containment methods for design and construction.

10. Develop design soil properties for engineering evaluations, including dynamic analysis.

11. Perform chemical assessment of groundwater and soil for the impact evaluation of existing soil and groundwater on foundation materials.

12. Substantiate the various baselines expressed in the Geotechnical Baseline Report for Bidding (GBR-B), consider those baselines in the development of the design and construction approaches, and fill in any missing information in the GBR-B accordingly to develop a Geotechnical Baseline Report for Construction (GBR-C).

10.A.2.3 Sequence of Geotechnical Investigations

Details on performing geotechnical investigations are provided in Section 10.A.2.4 and shall follow the general sequence listed below.

1. Review the scope of project requirements to obtain a clear understanding of project goals, objectives, constraints, values, and criteria. This information may consist of:
   - Project location, size and features
   - Project element type (bridge, tunnel, station, embankment, retaining wall, etc.)
   - Project criteria (alignments, potential structure locations, approximate structure loads, probable bridge span lengths and pier locations, and cut and fill area locations)
   - Project constraints (context-sensitive design issues, right-of-way, environmental and biological assessments and permitting)
   - Project design and construction schedules and budgets
2. Review of available geologic and geotechnical data.
3. Initiate and prepare geotechnical investigations plans. Identify the anticipated required analyses and key engineering input for the analyses.
4. Perform field reconnaissance and geological mapping.
5. Finalize the Geotechnical Investigation Plan (GIP) and submit to the Authority. Obtain permits and rights-of-entry.
6. Perform exploration and laboratory testing for final design.
7. Compile and summarize data for use in performing engineering analyses, and prepare geotechnical data reports, geotechnical engineering reports, and geotechnical baseline report for construction.

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10.A.2.4 Planning Geotechnical Investigations

The planning process for geotechnical investigations requires evaluating the appropriate number, depth, spacing, and type of exploration holes, as well as sampling intervals and testing frequencies. The involvement of engineering geologists (supporting the Geotechnical Designer) is critical throughout the investigation process, from initial exploration planning through the characterization of site conditions, to assure consistency for geologic interpretation of subsurface conditions in support of developing parameters for use in phased engineering design and construction.

The geotechnical investigation program shall be carried out in phases.

10.A.2.4.1 Desk Study

Review of subsurface conditions based on existing geological and subsurface data.

All relevant available information on the project site shall be reviewed. Available data may consist of reports, maps, journal articles, aerial photographs, historical records of previous investigations by agencies, as-built plans from construction of existing facilities, and communication with individuals with local knowledge. A Geologic Hazards Report shall be prepared by a California Certified Engineering Geologist (CEG) in advance of geotechnical investigations. The report shall be reviewed and utilized as a basis for geologic characterization and potential geologic hazards, and for siting of proposed subsurface exploration points. The results of the geologic and seismic hazard evaluation shall be collaborated with the Geotechnical Designer. Other sources of available information include the California Geological Survey (CGS), the United States Geological Survey (USGS), Caltrans archived Logs of Test Borings (LOTBs), the GIS database developed as part of the CHSTP, and data in individual city and county records and archives.

10.A.2.4.2 Field Reconnaissance

Field reconnaissance shall be conducted jointly by the Geotechnical Designer and the CEG after the desk study is completed. The following factors shall be evaluated by the field reconnaissance:

- Geologic Report Reviews – The Geotechnical Designer and Engineering Geologist responsible for the geotechnical investigations shall review and become familiar with geologic site characterizations and any identified geologic hazards provided in geologic hazards evaluation reports.
- Environmental Considerations – Potential impacts the project may have on subsurface materials, landforms, and the surrounding area shall be identified, and assessed to determine if project areas are governed by special regulations or have protected status.
- Explorations – The type(s) and amount of exploration and the kinds of samples that would best accomplish the phased project needs shall be evaluated.

- Drilling Logistics – The type, approximate locations, and depths of geotechnical explorations shall be defined, and approximate routes of access to each exploration location shall be determined. Make note of any feature that may affect the geotechnical investigation program, such as accessibility, structures, overhead utilities, evidence of buried utilities, or property restrictions. Evaluate potential water sources for use during borehole drilling operations. Evaluate potential concerns that may need to be addressed while planning an exploration program (permits, buried or overhead utilities clearance, equipment security, private property, etc.).
- Permits – The various types of permits that may be required shall be assessed, and all applicable jurisdictions shall be considered, which could include partner agencies, adjoining properties including railroads, Caltrans, regulatory agencies, and state and local government agencies. Local government agencies requirements could include regulations, codes, and ordinances from city, county, and departments of public works having jurisdiction. Permits could include right-of-entry, drilling and well permits, special use permits, lane closure and traffic control plans, utility clearances, etc.

10.A.2.4.3 General Subsurface Profiles

The general subsurface profiles, once developed, will present an overall geologic conditions of the areas under study and allow the Geotechnical Designer (in collaboration with the engineering geologist) to determine the locations of supplementary explorations for final design and construction.

10.A.2.4.4 Carry Out Geotechnical Investigations In Stages

For areas where there are no existing subsurface investigation data, conduct geophysical testing such as Spectral Analysis of Surface Wave (SASW), Multi-channel Analysis of Surface Wave, (MASW), Suspension PS Logging, Cross-hole Seismic Logging, seismic refraction tests, seismic reflection tests, or a combination of the above to measure shear wave and P-wave velocities in situ and to generalize the subsurface conditions prior to drilling CPTs and borings. The sequence of site investigation shall be as follows:

- Geophysical testing – To determine the general subsurface conditions for areas with no available existing geologic data.
- CPTs – To confirm the general subsurface conditions with measurements of pore water pressure and shear wave velocities with depth by means of using a combination of seismic cones, CPTu, and CPTs.
- Borings – To refine the general subsurface conditions after CPTs are performed. Install observation wells or piezometers and inclinometers where necessary to confirm groundwater table levels and ground movement in the field. Perform suspension PS logging or cross-hole seismic logging at deep boreholes (180 feet or deeper) in structures located over river crossings or unusual geologic conditions[1], and other boring locations selected by the Geotechnical Designer in collaboration with the engineering geologist.

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[1] Unusual Geologic Conditions **–** Structures that are subject to and founded on the following geologic conditions:

- Soft, collapsible, or expansive soil
- High groundwater table (within 5 feet below ground surface)
- Soil having moderate to high liquefaction and other seismically induced ground deformation potential
- Soil of significantly varying type over the length of the structure
- Fault Zones
- Unusual geologic conditions shall be defined within the Geotechnical Reports.

10.A.2.5 Surface Explorations

Standards for surface exploration methods are provided in PDDM Section 6.3.2.2, and technical guidance is provided in GTGM Section 3.2.2. Geologic field mapping of surficial soil and rock units and measurements of rock discontinuities shall begin by observing, measuring, and recording of exposed rock structure data at existing road cuts, drainage courses, and bank exposures, as well as portal locations where profiles transition from underground segments to elevated structures or at-grade reaches. Where rock exposures exist, mapping shall include initial characterization of rock mass rating, weathering, texture, overall quality, and discontinuity characteristics.

The objective of these observation and data collection efforts is to confirm the general types of soil and rock present, and topographic and slope features. For rock slopes, performance of slopes and the rockfall history are important indicators of how a new slope in the same material will perform. In addition to plotting data on a site plan or large-scale topographic map, preparation of field-developed cross sections is a valuable field method.

10.A.2.6 Subsurface Explorations

Relative advantages (economy, data quality, data collection time) of various methods of subsurface investigation should be considered in selecting the exploration plan. For example, geophysical methods and CPTs, which are relatively cheap and faster in operations, shall be conducted first, then followed by conventional test borings in specific situations.

Standards for performing subsurface explorations are provided in PDDM Section 6.3.2.2, and technical guidance is provided in GTGM Section 3.2.2. A guideline for the type of equipment and frequency of use for various types of investigations is presented in GTGM Exhibit 3.2-E. Additional guidance is contained in Caltrans (2007) logging manual.

The scope of the investigations shall reflect the anticipated subsurface and surface conditions and the preliminary results presented in the GDR during the bidding phase. Some factors that may impact the prioritization (sequence order ranking), method, number, and depth of subsurface explorations include the potential geologic hazards identified and geology (soil and rock units), landslides, slope stability, rockfall, rip-ability, fill suitability, expansive soils, compressible or collapsible soils, groundwater and hydrogeology, ground-borne vibration and noise transmissivity, erosion, temporary shoring, and excavation slopes. The level of

investigation, priority, and scope of work for each component shall be developed in accordance with the geotechnical investigation guidelines set forth in these guidelines.

- Geophysical Methods – Spectral Analysis of Shear Wave (SASW), Multi-channel Analysis of Shear Wave (MASW), suspension logging, or cross-hole seismic logging shall be conducted to measure in situ shear wave and primary (P) wave velocities with depth. Shear wave and P-wave velocities are the key dynamic properties for seismic design and shall be measured in situ during geotechnical investigations.

  Standards for geophysical methods are provided in PDDM Section 6.3.2.3.2. The primary source supporting the guidance is FHWA DTFH68-02-P-00083 Geophysical Methods Technical Manual (2003). Secondary sources are NHI 132031 and USACE EM 1110-1-1802. Generally, geophysical methods are used as a reconnaissance investigation to cover large areas and/or to supplement information between boreholes. These exploration techniques are most useful for extending the interpretation of subsurface conditions beyond what is determined from small-diameter borings. The methods presented in FHWA (2003) shown as Exhibit 3.2-F of the GTGM are some of the most common. The reliability of geophysical results can be limited by several factors, including the presence of groundwater, non-homogeneity of soil stratum thickness, gradation or density, and the range of wave velocities within a particular stratum. Subsurface strata that have similar physical properties can be difficult to distinguish with geophysical methods. Geophysical methods are also applicable for testing ground-borne vibration transfer mobility of subsurface conditions, and assessment of this parameter is considered important for HST systems. The reference document for this testing is titled, "High-Speed Ground Transportation Noise and Vibration Impact Assessment," FRA Report No. 293630-1, December 1998.

- Cone Penetration Test, Seismic Cones, and Piezocone Penetrometer Test – CPT is a specialized quasi-static penetration test where a cone on the end of a series of rods is pushed into the ground at a constant rate and continuous or intermittent measurements are made of the resistance to penetration of the cone. This test can be used in sands or clays, fibrous peat or muck that are sensitive to sampling techniques, but not in rock, dense to very dense sands, or soils containing appreciable amounts of gravel, and cobble. The CPT is relatively inexpensive in comparison to borings, but it can only be used to supplement sampled borings because no samples are obtained so that no positive identification of soil types can be made out of the CPTs.

  Piezocones are electric penetrometers that are capable of measuring pore-water pressures during penetration. When equipped with time-domain sensors, cones can also be used to measure shear wave velocity.

  Tests are conducted in accordance with ASTM D 5778 (Standard Test Method for Electronic Friction Cones and Piezocone Penetration Testing of Soils). References: Guides to CPT (Robertson, 2010), TRB-NCHRP synthesis report 368 (2007), and FHWA-SA-91-043.

  Many correlations relating CPT data to soil types and engineering properties have been published. These correlations can be used for design of spread footings and piles.

- Test Borings – Guidance for selection of the applicable exploration methods is presented in PDDM Exhibit 6.3-A (borings). Methods for exploratory borings shall be in accordance with AASHTO and ASTM standards. Detailed information on drilling and sampling methods is given in NHI132031 which lists applicable American Association of State Highway and Transportation Officials (AASHTO) and ASTM drilling and sampling specifications and test methods. Additional references include AASHTO MSI-1, FHWA GEC-5, FHWA-ED-88-053, National Highway Institute (NHI) 132012, NHI132035, USACE EM 1110-1-1804, USACE EM 1110-1-1906, FHWA-FL-91-002, and Caltrans (2007).

  For the rotary wash drilling method, the drilling fluid in boreholes shall be kept above the groundwater level at all times. Rapid fluctuations in the level of drilling fluids shall be avoided. The boreholes shall be thoroughly cleaned prior to taking samples. Drill cuttings shall be collected and disposed of in accordance with applicable regulations.

  Disturbed samples can be used for determining the general lithology of soil deposits, for identifying soil components and general classification purposes, and for determining grain size, Atterberg limits, and compaction characteristics of soils. The most commonly used in-situ test for surface investigations is the Standard Penetration Test (SPT), AASHTO T 206. The use of automatic hammers for SPT is highly recommended, and standard drop height and hammer weight must be maintained. The SPT values obtained with non-automatic hammers are discouraged and are allowed when calibrated by field comparisons with standard drop hammer methods. The SPT dynamic analyzer shall be used to calibrate energy of the SPT equipment at the site at least at the start of the project and bi-weekly for long-duration site investigations. More frequent use of the SPT dynamic analyzer is encouraged.

  Undisturbed samples shall be obtained in fine-grained soil strata for use in laboratory testing to determine the engineering properties of those soils. Specimens obtained by undisturbed sampling methods may be used to develop the strength, stratification, permeability, density, consolidation, dynamic properties, and other engineering characteristics of soils. Disturbed and undisturbed samples can be obtained with a number of different sampling devices, as summarized in Table 7 of FHWA GEC-5 and Table 3-4 of NHI 132031.

  It will be the responsibility of the Geotechnical Designer to obtain enough testable samples of rock and soil to complete the agreed-upon laboratory testing program. The quantity of each type of test conducted shall be proposed by the geotechnical investigation consultant to adequately characterize each soil or rock unit encountered. Therefore, adequate subsurface exploration and sampling will be necessary to obtain sufficient sample quantity for subsurface characterization.

  - Sandy or Gravely Soils Sampling – The SPT (split-spoon) samples shall be taken at 5-foot intervals or at significant changes in soil strata. Continuous SPT samples with a gap of at least 6 inch between two consecutive tests are recommended in the top 15 feet of borings made at locations where spread footings may be placed in natural soils. SPT

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bagged samples shall be sent to lab for classification testing and verification of field visual soil identification. Modified California (MC) and/or California (C) samplers shall not be used in these soils.

- Silt or Clay Soils and Peat Sampling – The SPT and undisturbed thin wall tube samples shall be taken at 5-foot intervals or at significant changes in strata of cohesive soils. Hydraulic (Osterberg) thin-walled piston samplers shall be used in collecting soft to very soft clays. Take alternate SPT and tube samples in same boring or take tube samples in separate undisturbed boring. Tube samples shall be sent to lab to allow consolidation testing (for settlement analysis) and strength testing (for slope stability and foundation-bearing capacity analysis). The tube samples shall be retrieved by pushing soil out in the same direction that it entered the tube (i.e., through the top of the tube sampler; do not reverse and push it back out of the bottom). Field vane shear testing is also recommended to obtain in-place shear strength of soft clays, silts, and peat.
- Rock Sampling – Continuous cores shall be obtained in rock or shales using double- or triple-tube core barrels. In structural foundation investigations, core a minimum of 10 feet into rock to ensure it is bedrock and not a boulder. Core samples shall be sent to the lab for possible strength testing (unconfined compression) if for foundation investigation. Percent core recovery and rock quality designation (RQD) value shall be determined in field or lab for each core run and recorded on the boring log. Additional guidelines for rock coring are described later in this section and in the reference manuals.
- Groundwater in Borings – Water level encountered during drilling, at completion of boring, and at 24 hours after completion of boring shall be recorded on the boring log. In low permeability soils such as silts and clays, a false indication of the water level may be obtained when water is used for drilling fluid and adequate time is not permitted after boring completion for the water level to stabilize (more than one week may be required). In such soils, a plastic pipe water observation well shall be installed to allow monitoring of the water level over a period of time. Seasonal fluctuations of water table shall be determined where fluctuation will have significant impact on design or construction (e.g., borrow source, footing excavation, excavation at toe of landslide). Artesian pressure and seepage zones, if encountered, shall also be noted on the boring log. In landslide investigations, slope inclinometer casings can also serve as water observation wells by using leaky couplings (either normal aluminum couplings or PVC couplings with small holes drilled through them) and pea gravel backfill. The top 1 foot or so of the annular space between water observation well pipes and borehole wall shall be backfilled with grout, bentonite, or sand-cement mixture to prevent surface water inflow, which can cause erroneous groundwater level readings.

- Probes, Test Pits, Trenches, and Shafts – Guidance for selection of the applicable exploration methods is presented in PDDM Exhibit 6.3-B (probes, test pits, trenches, and shafts), and GTGM Section 3.2.3.5. The recommended primary reference is NHI 132031.

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Additional guidance is contained in AASHTO MSI-1 and Caltrans 2007. Exploration pits and trenches performed by hand, backhoe, or dozer allow detailed examination of the soil and rock conditions at shallow depths and relatively low cost. Exploration pits can be an important part of geotechnical explorations where significant variations in soil conditions occur (vertically and horizontally), large soil and/or non-soil materials exist (boulders, cobbles, debris) that cannot be sampled with conventional methods, or buried features must be identified and/or measured. Upon completion, the excavated test pit shall be backfilled and compacted with the excavated material or other suitable soil material, and the surface shall be restored to its previous or approved condition.

- Soil Resistivity Testing – The ability of soils to conduct electricity can have a significant impact on the corrosion of buried structures and the design of grounding systems. Accordingly, subsurface investigations shall include conducting appropriate investigations to obtain soil resistivity values. The following information and methodologies are recommended.
  - Soil resistivity readings shall be obtained to determine the electric conduction potential of soils at each traction power facility (supply/paralleling/switching station), which are spaced at approximately 5-mile intervals.
  - Resistivity measurements shall be obtained in accordance with Institute of Electrical and Electronics Engineers (IEEE) Standard 81-1983 - IEEE Guide for Measuring Earth Resistivity using the four-point method for determining soil resistivity. IEEE states that the four-point method is more accurate than the two-point method.
- Standards for Boring Layout and Depth – Standards for boring layout and depth with respect to structure types, locations and sizes, and proposed earthwork are provided in these guidelines.
- Standards for Sampling and Testing From Borings – Minimum standards for disturbed and undisturbed soil and rock are presented in Exhibit 6.3-D of PDDM, and Section 3.2.3.3 of GTGM.
- Rock Coring – Standards for soil and rock classification are provided in PDDM Section 6.3.2.3.4, and technical guidance is provided in GTGM Section 3.2.3.4. The International Society of Rock Mechanics (ISRM) classification system shall be followed for rock and rock mass descriptions, as presented in FHWA GEC-5 FHWA-IF-02-034. The primary source supporting the standards and guidance is NHI 132031, and a secondary source is AASHTO MSI-1. Because single-tube core barrels generally provide poor recovery rates, the double- or triple-tube core barrel systems shall be used. To protect the integrity of the core from damage (minimize extraneous core breaks), a hydraulic ram shall be used to expel the core from the core barrel. Rock cores shall be photographed in color as soon as possible after being taken from the bore hole and before laboratory testing.

If rock is encountered in boreholes within the planned depth of drilling, continuous rock coring shall be performed in accordance with the following procedures. Rock coring shall be performed using a double or triple tube HQ coring system or a larger-diameter, double or

triple-tube coring system. The HQ system produces cores 2.4 inches in diameter. The advantage of the triple tube system is that a split liner is used to contain the core, which results in relatively minimal disturbance to the core. Where weak rock zones are encountered, soil sampling techniques may be used instead of coring to recover samples that would be relatively undisturbed and suitable for testing. These techniques include the use of samplers such as the Pitcher or MC samplers. The potential difficulty with these samplers is that they can be easily damaged by hard, gravel-size particles that are often mixed with the softer, clay-like matrix of the weathered rock. These difficulties will need to be considered when planning the exploration program.

Rock core samples shall be placed in plastic core bags or double wrapped in plastic wrap and placed in wooden core boxes and transported to a storage facility at the end of each day. An adequate number of core boxes shall be maintained on site at all times during field exploration activities. The core shall be photographed, taking at least one photo for each core box, and close-ups taken of special features such as shear zones or other features of special interest. The core box label shall be clearly visible within the photo. An experienced geologist shall study the core and edit the borehole log based on their observations. Cores boxes shall be maintained throughout the design process and construction, with cores that have been removed for testing duly indicated in the appropriate locations in each box.

In some rock slope applications, it is important to understand the precise orientation of rock discontinuities for the design. Standards for using orienting-recovered rock core are presented in NHI 132031. In special cases, boreholes can be photographed/imaged to visually inspect the condition of the sidewalls, distinguish gross changes in lithology, and identify fracture zones, shear zones, and joint patterns by using specialized television cameras. Refer to AASHTO MSI-1, Section 6.1.2.

- Care and Retention of Samples – Technical guidelines for soil and rock retention are provided in GTGM Section 3.2.3.7, and geotechnical boring and sample identification, handling and storage guidelines are provided in each Contract.

10.A.2.7 Soil and Rock Classification

Standards for soil and rock classification are provided in PDDM Section 6.3.2.4, and technical guidance is provided in GTGM Section 3.2.4. Soils shall be classified in accordance with the ASTM Unified Soil Classification System (USCS). Rock and rock mass descriptions and classification shall follow the ISRM classification system presented in FHWA GEC-5. Material descriptions are based on the visual-manual method, and materials classifications are based on laboratory index tests (ASTM D 2487). Additional guidance is contained in Caltrans Soil and Rock Logging, Classification, and Presentation Manual (2007).

10.A.2.8 Exploration Logs

Standards for preparing exploration field logs are provided in PDDM Section 6.3.2.5, and technical guidance is provided in GTGM Section 3.2.5.

- Field Logs – Field logging shall be performed by a geologist or engineer under the direct supervision of a California registered geotechnical engineer or CEG. Logging shall be performed in accordance with ASTM D 5434. The location information (e.g., station, offset, elevation, and/or state plane coordinates) of all the explorations are to be recorded on the field logs. Exploration locations shall be located at the time of drilling by GPS with at least sub-10-foot accuracy. The explorations shall eventually be located by a licensed land surveyor. Required documentation for test pits shall include a scale drawing of the excavation, and photographs of the excavated faces and spoils pile. Drilling and sampling methods and in-situ measurement devices that were used shall also be documented. The field logs shall contain basic reference information at the top, including project name, purpose, specific location and elevation, exploration hole, number, date, drilling equipment, procedures, drilling fluid, etc. In addition to the logging descriptions of soil and rock encountered during exploration, the depth of each stratum contact, discontinuity, and lens shall be recorded. The reason for terminating an exploration hole and a list/description of instrumentation (if any) or groundwater monitoring well installed shall be written at the end (bottom) of each exploration log.
- Final Logs – Exploration logs shall be prepared with the gINT boring/test pit log software platform, using the formatted boring record template standardized by Caltrans (illustrated as Figures 5-12 and 5-13 in the Caltrans logging manual, 2007 version). An explanation key, known as the Boring Record Legend shall always accompany exploration logs whenever they are presented. The standardized legends to be used for CHSTP are illustrated as figures 5-14 through 5-16 of Caltrans (2007). The final edited log shall be based on the initial field log, visual classification, and the results of laboratory testing. The final log shall include factual descriptions of all materials, conditions, drilling remarks, results of field and lab tests, and any instrumentation. Where groundwater observation wells or piezometers are installed, several measurements are usually necessary within a one-week timeframe following drilling to verify that measured groundwater levels or pressures have achieved equilibrium. As a minimum, final boring logs shall contain the information shown in NHI132031. AASHTO MSI-1 provides additional guidance regarding documentation for boring logs.

10.A.2.9 In-Situ Testing

Standards for performing in-situ testing are provided in PDDM Section 6.3.2.6, and technical guidance is provided in GTGM Section 3.2.6. The primary reference is NHI1 32031. In-situ testing is very beneficial for projects where obtaining representative samples suitable for laboratory testing is difficult. Field in-situ borehole tests can be correlation tests, strength and deformation tests and permeability tests. Correlation tests primarily consist of SPTs performed in accordance with ASTM D 1596 and AASHTOT 206, and Dynamic CPTs are performed in accordance with ASTM D 3441.

- In-situ soil tests may consist of the following:

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- Cone Penetration Test (CPT) – Refer to Section 10.A.2.6.
- Pressuremeter Test – This test measures state of stress in-situ and stress/strain properties of soils by inflating a probe placed at a desired depth in a borehole. Tests are completed in accordance with ASTM D 4719. Reference FHWA-IP-89-008.
- Flat-Plate Dilatometer Test – This test uses pressure readings from an inserted plate at the base of a borehole to determine stratigraphy and obtain estimates of at-rest lateral stresses, elastic modulus, and shear strength of loose to medium dense sands (and to a lesser degree, silts and clays). Tests are completed in accordance with ASTM D 6635. Reference FHWA-SA-91-044. Care and judgment shall be undertaken for this test as it often provides information that is difficult to interpret or relate to parameters needed for engineering design.
- Field Vane Shear Test (VST) – This test is used on very soft to medium stiff cohesive soil or organic deposits to measure the undrained shear strength, remolded strength of the soil and soil sensitivity. Field vane shear test may provide more reliable estimate of peak and residual shear strength in cohesive soils, as disturbance from sampling and testing in laboratory is avoided. Tests are completed in accordance with ASTM D 2573 and AASHTO 223. VST is often regarded as a valuable test to estimate peak and residual shear strength in cohesive soils as disturbance from sampling and testing in the laboratory can be avoided.

- Hydrogeologic testing in-situ may consist of the following:
  - Permeability Tests – Several in-situ hydraulic conductivity tests exist, with the most commonly used methods being the pumping test and the slug test. The selection of the appropriate aquifer test method for determining hydraulic properties by well techniques is described in ASTM D 4043. In general, refer to NHI1 32031, BOR Geology Manual, and NAVFACDM-7.1.
  - Pumping Test – The pumping test requires not only a test well to pump from, but also one to four adjacent observation wells to monitor the changes in water levels as the pumping test is performed. Pumping tests are typically used in large-scale investigations to more accurately measure the permeability of an area for the design of dewatering systems. Refer to ASTM D 4050.
  - Slug Test – The slug test is quicker to perform and much less expensive, because observation wells are not required. It consists of affecting a rapid change in the water level within a well by quickly injecting or removing a known volume of water or solid object, known as a slug. The natural flow of groundwater out of or into the well is then observed until equilibrium in the water level is obtained. Refer to ASTM D 4044.
  - Packer Tests – These tests are performed in a borehole by placing packers above and below the soil/rock zone to be tested. One method is to remove water from the material being tested (Rising Water Level Method). Another method is to add water to the borehole (Falling Water Level Method and Constant Water Level Method). A third

method utilizes water under pressure rather than gravity flow. The coefficient of permeability that is calculated provides a gross indication of the overall mass permeability. Refer to FHWA-TS-89-045 and NHI1 32031.

- Open Borehole Seepage Tests – Methods include "Falling Water Level," "Rising Water Level," and "Constant Water Level" and are selected based on the relative permeability of the subsurface soils and groundwater conditions. Further detail is provided in Chapter 6 of NHI1 32031.
- Infiltration Tests – Two types of infiltrometer systems are available: sprinkler type and flooding type. Sprinkler types attempt to simulate rainfall, while the flooding type is applicable for simulating runoff conditions. Applications for these tests include the design of subdrainage and dry well systems. The most common application is the falling head test, performed by filling (flooding) a test pit hole and monitoring the rate at which the water level drops. Refer to ASTM D 4043.

Handling and disposal (or permitted discharge to storm sewer system) of water generated from hyrdrogeologic field testing shall be the responsibility of the Geotechnical Designer conducting the investigation work.

If the Geotechnical Designer intends to use field tests not covered in the current ASTM or referenced standards, the proposed test methods shall be submitted to the Authority for approval prior to start of testing.

10.A.2.10 Laboratory Testing of Soil and Rock

Standards for performing laboratory testing are provided in PDDM Section 6.3.2.7 and technical guidance is provided in GTGM Section 3.2.7. Sufficient laboratory testing shall be performed to represent in-situ conditions. Exhibit 3.2-J of the GTGM provides a guideline for estimating laboratory test requirements for the different types of geotechnical analysis. Chapters 7 through 10 of NHI 132031, GEC-5, and Chapters 2 and 3 of NHI 132012 provide overviews of testing and correlations, as well as criteria to consider when planning the scope of testing programs. Additional references include AASHTO MSI-1, NHI 132012, NHI 132035, USACE EM 1110-2-1906, FHWA-FL-91-002; and Kulhawy and Mayne (1990). Exhibits 3.2-K (soil) and Exhibit 3.2-L (rock) of GTGM present a summary of the predominant laboratory tests. The proposed workplans for laboratory testing programs shall be submitted for review. Testing shall be done at a Caltrans approved facility.

If the Geotechnical Designer proposes to use laboratory tests not covered in the current ASTM or referenced standards, a variance of test methods shall be submitted to the Authority for approval prior to commencement.

10.A.2.11 Instrumentation and Monitoring

Standards for installing and monitoring geotechnical instrumentation are provided in PDDM Section 6.3.2.8, and technical guidance is provided in GTGM Section 3.2.8. Instrumentation is

used to augment standard investigation practices and visual observations where conditions would otherwise be difficult to evaluate or quantify due to location, magnitude, or rate of change. The quantity and locations of proposed geotechnical instrumentation shall be selected to suit the anticipated conditions consistent with project objectives and design requirements. The geotechnical exploration work plan shall include instrumentation work detailing locations, installation procedures, and methods to be used. The work plan shall be submitted to the Authority prior to commencement. Additional information about inclinometers and piezometers are presented in Cornforth (2005).

10.A.3 Project Features Requiring Geotechnical Investigations

10.A.3.1 General

The CHSTP will require geotechnical investigations of the various project features. The referenced standards and technical guidance documents shall be utilized, in addition to the primary and secondary references, where listed. Guidelines for the approximate number and depth of various exploration methods are included. In addition to the general guidelines, the scope of the investigation for the various project features shall also reflect the anticipated subsurface and surface conditions, as well as the design phase level (whether preliminary or final). Some factors that may impact the method, number, depth, and prioritization of subsurface explorations include type of soil or rock, landslides, slope stability, rockfall, rippability, fill suitability, expansive soils, compressible soils, groundwater and hydrogeology, ground-borne vibrations, erosion, engineering design needs, temporary shoring, and excavation slopes.

The scope of investigation work for each component shall be developed in accordance with the guidelines contained in this section. The quantity, locations, and depths of proposed geotechnical exploration shall be selected to suit the anticipated conditions consistent with phased project objectives and design requirements. The geotechnical exploration work plan shall include information detailing methods to be used and proposed schedule. The work plan shall be submitted to the Authority prior to commencement. If the Geotechnical Designer proposes to use exploration methods or frequencies that differ from the guidelines set forth herein or are not covered in the current reference standards, a variance for the proposed alternate exploration plans shall be submitted to the Authority for approval prior to commencement.

The geophysical testing and CPTs provide advantages over conventional test borings under specific situations and should be considered first.

10.A.3.2 Rail Alignment and Earthwork

Standards for investigations for the at-grade rail alignment and earthwork are provided in PDDM Section 6.3.1.2.1, and technical guidance is provided in GTGM Section 3.1.2.1.

Explorations are made along the proposed at-grade rail alignment for the purpose of defining the geotechnical properties of materials. This information is used to:

- Design cut and fill slopes
- Assess material suitability for embankment construction
- Define the limits of potential borrow materials
- Assess the suitability of foundation materials
- Evaluate settlement or slope stability problems
- Quantify the depths of topsoil and volumes of material to be removed
- Design remedial measures in areas of poor materials
- Aid the designer of the rail roadbed subgrade section
- Identify geologic hazards such as liquefaction and landslides

For cuts and fills, test borings shall be advanced at least every 200 feet (erratic conditions) to 400 feet (uniform conditions) along the project alignment where cuts or fills are anticipated. For large cuts or fills (e.g., 30 feet or more in height) an additional boring near the top of the proposed cut and toe of the proposed fill to evaluate cut/fill feasibility and overall stability may be necessary. Depths of the borings shall be at least three times the vertical height of the fill (or 40-foot minimum depth) and at least 15 feet below the base of the cut. If soft or poor soils are encountered, additional depth to competent material or 10 feet into rock will be needed to define the subsurface conditions.

10.A.3.3 Structures

Standards for structures and geotechnical hazards are provided in PDDM Section 6.3.1.2.3, and technical guidance is provided in GTGM Section 3.1.2.3 and Exhibit 3.1-B Guideline "Minimum Boring" Criteria. Structures and geotechnical hazards will primarily consist of the following:

- Bridges and aerial structures (viaducts)
- Stations
- Buildings
- Retaining walls
- Tunnels and portals
- Large culverts
- Mast-arm supports (OCS, signals, message signs)
- Landslides
- Faults

For bridges, one boring shall be drilled at the substructure unit under 100 feet in width and two borings per substructure unit over 100 feet in width, both drilled to a depth of 20 feet below pile/shaft tip elevation or two times maximum pile group dimension, whichever is greater or to a depth of a minimum of 10 feet into bedrock. In addition, at least one seismic cone, suspension PS logging, or SASW shall be conducted at each bridge to measure shear wave and P-wave velocities in situ, each to a depth of 100 feet or deeper. The number of the seismic cones, suspension loggings, and SASW shall increase if the bridge is of multiple long spans (greater than 350 feet) and/or if the bridge is located in erratic soil conditions with soft, compressible and loose saturated soils.

For buildings and stations, one boring shall generally be made at each corner and one in the center. This may be reduced for small buildings. For extremely large buildings and stations or highly variable site conditions, one boring shall be taken at each support location. Refer to building foundation manuals and CBC (codes) for additional guidance in planning geotechnical investigations. In addition, areas of influence of the building/station and/or of surrounding geologic or geotechnical issues shall be considered in defining the extent of explorations.

For retaining walls, the minimum site exploration will be one boring or one CPT (or both) at 100 to 200 foot intervals, each drilled to a depth of 0.75 to 1.5 times wall height or to a competent stratum if potential deep stability or settlement is a problem. The boring and CPT can be interchangeable and located at the front of and some in back of the wall face.

Due to the extreme variability of conditions under which tunnels are constructed and the complexity of the projects, it is difficult to provide specific recommendations for tunnel investigation criteria. In general, boring footage is typically on the order of 1.5 to 3.0 linear feet of borehole per route foot of tunnel, and site exploration budgets are typically on the average of three percent of the estimated tunnel cost. Criteria shall be established for each project reach on an individual basis and be based on the complexity of the geology and the length and depth of the tunnel. FHWA-IF-05-023 and U. S. National Committee on Tunneling (USNCTT, 1995) shall be considered the primary references.

For culverts, a minimum of 1 boring per major culvert drilled to a competent stratum or to a depth of twice the culvert height, whichever is less.

Standard foundations for sign bridges, cantilever signs, cantilever signals, and strain pole standards are based on allowable lateral bearing pressure and angle of internal friction of the foundation soils. The determination of these values may be estimated by SPT and CPT. One CPT or one boring shall be made at each designated location. Cones shall be drilled to at least 50 feet into firm ground. Borings shall extend 50 feet into suitable soil or 5 feet into competent rock. Deeper borings may be required for posts with higher torsional loads or if large boulders are anticipated. Other criteria are the same as for bridges.

In addition to the above structures, any structure such as signage or other design features shall be addressed with regard to their potential influence and evaluated, as needed.

10.A.3.4 Landslides – Slope Instability

Standards for investigations for landslides are provided in PDDM Section 6.3.1.2.4, and technical guidance is provided in Section 3.1.2.4 and Exhibit 3.1-B of the GTGM. A minimum of three borings shall be advanced along a line perpendicular to centerline or planned slope face to establish geologic cross sections for stability analysis. The number of cross sections depends on the extent of the slope stability problem. For active slides, place at least one boring each above and below the sliding area. The borings shall be extended to an elevation below active or potential failure surfaces and into hard stratum, or to a depth for which failure is unlikely because of geometry of the cross section. If slope inclinometers are used to locate the depth of an active slide, they must extend to a depth below the base of the slide. Observation wells and/or piezometers at selected depths will also be required to determine the groundwater table in the soil/rock mass.

10.A.3.5 Faults

At locations where active faulting is suspected to be coincident with or within the area of CHSTP operations and facilities, a geologic reconnaissance will be required to ground-truth mapped fault traces. This reconnaissance shall be carried out by means of interpretations of aerial photos, LiDAR data, satellite imagery, and topographic information. The locations shall be reviewed in the field to assess the presence of geomorphic features associated with faulting such as escarpments, pressure ridges, sag ponds, seeps/springs, vegetation contrasts, or deflected drainages. All such features shall be documented on a geologic field map. If sufficient field data is available to document that the fault or fault zone is outside the footprints of the high-speed train operations, no further fault evaluation is required. Otherwise, a site specific investigation including paleo-seismic trenching will be necessary.

If existing paleo-seismic trenching data is available, it may be reviewed and used as a basis for locating the fault and providing its rupture characteristics for final design; however, if either a known active fault or suspected active fault is located near or at the location of a project facility, exploratory trenching across the fault will be required to assess its rupture characteristics for input to final design.

10.A.3.6 Materials Sources

Standards for investigations for materials sources are provided in PDDM Section 6.3.1.2.2, and technical guidance is provided in Section 3.1.2.2 and Exhibit 3.1-B of the GTGM. Borings shall be spaced every 100 to 200 feet. The depth of exploration shall extend 5 feet beyond the base of the deposit, or to a depth required to provide the needed quantity of borrow material. These investigations shall evaluate the quality and quantity of materials available at existing and prospective sources within the vicinity of a project. These materials could include gravel base, crushed surfacing materials, pavement and concrete aggregates, riprap, wall backfill, borrow excavation, and select backfill materials. The evaluation may consider existing government-

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owned material sources, existing commercial material sources, expansion of existing sources, and development of new material sources.

10.A.3.7 Hydrological Features – Infiltration and Detention Facilities

For surface hydrological features (infiltration or detention facilities) that may be needed, at least one boring per site shall be obtained to assess feasibility and define groundwater conditions. Boring depths will depend on the nature of the subsurface conditions encountered and the depth of influence of the geotechnical feature. Borings shall extend at least 20 feet below the likely base elevation of the facility, or five times the maximum anticipated ponded water depth, whichever is greater. Observation wells and/or piezometers shall be installed and monitored for at least 1 year to assess yearly highs and lows for the groundwater.

10.A.3.8 Pavement

Pavements are not a significant component of the HST trackway alignment design but will be an extensive design element for station areas, access roads, grade separations, and surface road reconstruction. Standards for investigations for pavement subgrade are provided in PDDM Chapter 6, Section 6.3.1.2.5 and Chapter 11, and technical guidance is provided in GTGM Section 3.1.2.5. Other sources supporting investigation standards and guidance are NHI 132031, AASHTO MSI-1, and FHWA GEC-5.

10.A.4 References

1. American Association of State Highway and Transportation Officials (AASHTO)
   - Manual on Subsurface Investigations, MSI-1, 1988.
   - Standard Recommended Practice for Decommissioning Geotechnical Exploratory Boreholes, AASHTO R 22-97, standard Specifications, 2005.
   - Specification for Transportation Materials and Methods of Sampling and Testing, Part II: Tests, HM-28-M, 2008.
2. American Society of Civil Engineers (ASCE) reference titled "Geotechnical Baseline Reports for Construction – Suggested Guidelines", ASCE 2007.
3. American Railway Engineering and Maintenance of Way Association (AREMA) – Manual for Railway Engineering, 2008 Edition.
4. ASTM, Annual Book of ASTM Standards, 2008 Edition.
5. Caltrans, Soil and Rock Logging, Classification, and Presentation Manual, June 2010.
6. Cornforth, D.H., Landslides in Practice: Investigations, Analysis, and Remedial/Preventive Options in Soils, Chapter 4, John Wiley & Sons 2005.
7. Federal Highway Administration (FHWA):
   - Geotechnical Technical Guidance Manual, May 2007.

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- Project Development and Design Manual (Draft) – Chapter 6 - Geotechnical, April 2011.
- Checklist and Guidelines for Review of Geotechnical Reports and Preliminary Plans and Specifications, FHWA-ED-88-053, 1988, revised February 2003.
- Road Tunnel Design Guidelines, FHWA-IF-05-023, 2004.
- Geophysical Methods - Technical Manual (Application of Geophysical Methods to Highway Related Problems, cooperatively with Blackhawk Geosciences), DTFH68-02-P-00083, 2003.
- Soils and Foundations Workshop, NHI Course No. 132012, Volumes I and II FHWA-NHI-06-088, and FHWA-NHI-06-089, 2006.
- Subsurface Investigations – Geotechnical Site Characterization, NHI Course Manual No. 132031, FHWA-NHI-01-031, 2002.
- Evaluation of Soil and Rock Properties, Geotechnical Engineering Circular No. 5, FHWA-IF-02-034, 2002.

8. Federal Railroad Administration (FRA), High-Speed Ground Transportation Noise and Vibration Impact Assessment, FRA Report No. 293630-1, December 1998.
9. ISRM, Suggested Methods for the Quantitative Description of Discontinuities in Rock Masses, 1981.
10. Kulhawy, F.H. and Mayne, P.W., Manual on Estimating Soil Properties for Foundation Design, EPRI Report EL-6800, 1990.
11. U. S. Army Corps of Engineers (USACE), Geotechnical Investigations, Engineering Manual, EM 1110-1-1804, Department of the Army, 2001.
12. U. S. Army Corps of Engineers (USACE), Soil Sampling, Engineering Manual, EM 1110-1-1906, Department of the Army, 1996.

Appendix 10.B: Guidelines for Geotechnical Earthquake Engineering

10.B.1 Purpose

These guidelines represent a preferred, but not necessarily the only required actions needed for a particular design feature associated with earthquake engineering. These guidelines convey a minimum standard of care in performing earthquake engineering design. These are not intended as a prescribed design criteria or checklist.

10.B.2 Seismic Design Criteria

Seismic design criteria for geotechnical earthquake engineering have been established in terms of two levels of project performance criteria: No Collapse Performance Level (NCL) and Operability Performance Level (OPL) as noted in the *Seismic* chapter of the Design Criteria.

Geotechnical seismic design shall be consistent with the philosophy for structural design for the two performance levels. The performance objective shall be achieved at a seismic risk level that is consistent with the seismic risk level required for that seismic event. Slope instability and other seismic hazards such as liquefaction, lateral spread, post-liquefaction pile downdrag, and seismic movement/settlement may require mitigation to ensure that acceptable performance is obtained during a design seismic event. The Geotechnical Designer shall evaluate the potential for differential movement/settlement between mitigated and non-mitigated soils. Additional measures may be required to limit differential movement/settlements to tolerable levels both for static and seismic conditions. The foundations shall be designed to address liquefaction, lateral spread, and other seismic effects to prevent collapse. All earth-retaining structures shall be evaluated and designed for seismic stability internally and externally. Cut slopes in soil and rock, fill slopes, and embankments, especially those which could have significant impact on high-speed train (HST) operation, shall be evaluated for instability due to design seismic events and associated geologic hazards.

10.B.2.1 Liquefaction Triggering and Consequences

Evaluation of soil liquefaction triggering potential shall be performed in two steps. The first step involves evaluating whether the soil meets the compositional criteria necessary for liquefaction. These compositional criteria are presented in Section 10.12.2 of the *Geotechnical* chapter.

For soils meeting the compositional criteria, the next step is to evaluate whether the design level ground shaking is sufficient to trigger liquefaction given the soil's in-situ density. If it is assessed that liquefaction will be triggered, the engineering consequences of liquefaction shall be evaluated. In addition to triggering for liquefaction, the Geotechnical Designer shall consider

the allowable deformation and the long-term, post-construction performance requirements for earth and fill conditions.

For fine-grained soils (especially soils that are potentially sensitive) that do not meet the compositional criteria for liquefaction, the impact of cyclic softening resulting from seismic shaking shall be evaluated.

Considering the range of criteria currently available in the literature, the Geotechnical Designer shall consider performing cyclic triaxial or simple shear laboratory tests on undisturbed soil samples to assess cyclic response for critical cases.

For gravels, field investigation methods appropriate for soil layers containing gravels include the Becker Hammer Penetration Test (BPT), Large Sampler Penetration Test (LPT), and small interval SPT. Seed et al. (2003) discusses different methods for performing liquefaction analysis in coarse and gravelly soils.

10.B.2.2 Liquefaction Triggering Evaluations

Liquefaction-triggering evaluations shall be performed for sites that meet the two design criteria established in the *Geotechnical* chapter:

CPT and/or CPTu (with pore water pressure measurement) shall be used as the primary method of field investigation for liquefaction analysis where it can be advanced without premature refusal. Where CPT data are unavailable, SPT values can be used as the liquefaction evaluation method where borings are performed. LPT, shear wave velocity (Vs), or BPT shall be used in soils difficult to test using SPT and CPT methods, such as gravelly soils. In addition, small interval SPT (blow counts measured for every 1 inch) shall be used in gravelly soils. More rigorous, nonlinear, dynamic, effective stress computer models may be used for site conditions or situations that are not modeled well by the simplified methods.

10.B.2.2.1 Simplified Procedures

All three simplified methods by Youd et al. (2001), Seed et al. (2003), and Idriss and Boulanger (2008) shall be used for liquefaction-triggering analysis for each boring and/or CPT. Results in terms of FOS shall be reported. Results of these analyses shall be interpreted according to the following. If the FOS values between the three methods are within 20% of each other, an average FOS shall be reported for that particular boring and/or CPT. If the FOS values from these three methods vary by more than 20% and use of the more conservative results for design would have significant cost consequences, some additional evaluations may be warranted. The additional evaluations shall include an assessment of which method best applies to this specific case, additional soil-specific field and laboratory testing, and/or review by an expert panel.

The potential consequences of liquefaction and (if necessary) liquefaction hazard mitigation measures shall be evaluated if the FOS against liquefaction is less than 1.05.

10.B.2.2.2 Liquefaction-Induced Movement/Settlement

Both dry and saturated deposits of loose granular soils tend to densify and settle during and/or following earthquake shaking. Methods to estimate movement/settlement of unsaturated granular deposits are presented in Section 10B.2.8. Liquefaction-induced total ground settlement of saturated granular deposits shall be estimated using Zhang et al. (2002) and at least one of the following methods: Ishihara and Yoshimine (1992), Idriss and Boulanger (2008), and Cetin et al. (2009). If a laboratory-based analysis of liquefaction-induced settlement is needed, laboratory cyclic triaxial shear or cyclic simple shear testing may be used to evaluate the liquefaction-induced vertical settlement in lieu of empirical SPT- or CPT-based criteria. Even when laboratory-based volumetric strain test results are obtained and used for design, the empirical methods shall be used to qualitatively check the reasonableness of the laboratory test results.

It should be noted that all of these estimates are free-field settlements, and structural movement/settlements resulting from soil liquefaction are more important in most of the cases (Bray and Dashti, 2010). Structural movement/settlements may also result from shear-induced movements. Hence, methods that are used for estimating lateral ground movements may be required.

10.B.2.2.3 Liquefied Residual Strength Parameters

Unless soil-specific laboratory performance tests are conducted as described later in this section, residual strengths of liquefied soil shall be evaluated using at least two of these procedures: Seed and Harder (1990), Idriss and Boulanger (2008), Olson and Stark (2002), and Kramer and Wang (2011). Design liquefied residual shear strengths shall be based on weighted average of the results; Ledezma and Bray (2010) may be used as a reference to select a reasonable weighting scheme.

Results of laboratory cyclic triaxial shear or cyclic simple shear testing may be used to evaluate the residual strength in lieu of empirical SPT- or CPT-based criteria. Even when laboratory based test results are obtained and used for design, two of the above empirical methods shall be used to qualitatively check the reasonableness of the laboratory test results. It shall be noted that SPT N fines content corrections for residual strength calculations are different than corrections for liquefaction triggering and settlement.

10.B.2.2.4 Surface Manifestations

The assessment of whether surface manifestation of liquefaction (such as sand boils, ground fissures, etc.) will occur during earthquake shaking at a level-ground site that is not within a few hundred feet of a free face shall be made using the method outlined by Ishihara (1985) and shall be compared against results by the method presented in Youd and Garris (1995). It is emphasized that settlement may occur, even with the absence of surface manifestation. The Ishihara (1985) method is based on the thickness of the potentially liquefiable layer (H2) and the thickness of the non-liquefiable crust (H1) at a given site. In the case of a site with stratified soils

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containing both potentially liquefiable and non-liquefiable soils, the thickness of a potentially liquefiable layer (H2) shall be estimated using the method proposed by Ishihara (1985) and Martin et al. (1991). If the site contains potential for surface manifestation, then use of mitigation methods shall be evaluated.

10.B.2.3 Evaluation of Lateral Spreading and Consequences

Lateral spreading shall be evaluated for a site if liquefaction is expected to trigger within 50 feet of the ground surface, and either a ground surface slope gradient of 0.1% or more exists, or a free face conditions (such as an adjacent river bank) exists. Use Shamoto et al. (1998) as a method to assess the maximum distance from the free face where lateral spreading displacements could occur. Historic and paleoseismic evidence of lateral spreading is valuable information that shall also be reviewed and addressed. Such evidence may include sand boils, soil shear zones, and topographic geometry indicating a spread has occurred in the past.

10.B.2.3.1 Methodologies for Predicting Lateral Spreading

If there is a free face condition, the post-liquefaction flow failure FOS of an earth slope or sloping ground shall be estimated per Section 10B.2.9.1 below before estimating liquefaction-induced lateral movements. If the post-liquefaction stability FOS is less than 1.0 then empirical or analytical methods cannot generally be used to reliably predict the amount of ground movement.

In order to predict the permanent deformations resulting from the occurrence of lateral spreading during earthquake loading, several methods of analyses are available. These methods of analyses can be categorized into two general types: Empirical Methods and Analytical Methods.

Empirical Methods – The most common empirical methods to estimate lateral displacements are Youd et al. (2002), Bardet et al. (1999), Zhang et al. (2004), Faris et al. (2006) and Idriss and Boulanger (2008). Analysts shall be aware of the applicability and limitations of each method. Lateral displacements shall be evaluated using the Zhang et al. (2004) method and at least one of the other methods described above.

Empirical methods shall be used as the primary means to estimate deformations due to lateral spreading. Multiple models shall be considered, and the range of results shall be reported.

Analytical Methods – For cases where slope geometry, structural reinforcement, or other site-specific features are not compatible with the assumptions of the empirical methods, the Newmark sliding block analyses shall be used. Newmark analyses shall be conducted similar to that described in the seismic slope stability section, except that estimation of the yield acceleration (k_y) shall consider strength degradation due to liquefaction. In addition, numerical methods using finite elements and/or finite difference approach may be used.

The Geotechnical Designer shall compare the estimated lateral spread values with the allowable deformation values and develop mitigation plans described in Section 10B.2.4, if necessary. The Geotechnical Designer shall consider the long-term, post-construction performance requirements for earth-and-fill conditions.

10.B.2.4 Analysis for Design of Liquefaction Mitigation

During the liquefaction evaluation, the engineer shall evaluate the extent of liquefaction and potential consequences such as bearing failure, slope stability, and/or vertical and/or horizontal deformations. Similarly, the engineer shall evaluate the liquefaction hazard in terms of depth and lateral extent affecting the structure in question. The lateral extent affecting the structure will depend on whether there is potential for large lateral spreads toward or away from the structure and the influence of liquefied ground surrounding mitigated soils within the perimeter of the structure.

Large lateral spread or flow failure hazards may be mitigated by the implementation of containment structures, removal or treatment of liquefiable soils, modification of site geometry, structural resistance, or drainage to lower the groundwater table.

Where liquefiable clean sands are present, geotechnical evaluations for design shall consider an area of softening due to seepage flow occurring laterally beyond the limit of improved ground a distance of two-thirds of the liquefiable layer thickness, as described in studies by Iai et al. (1988). To calculate the liquefiable thickness, similar criteria shall be used as that employed to evaluate the issue of surface manifestation by the Ishihara (1985) method. For level ground conditions where lateral spread is not a concern or the site is not a water front, this buffer zone shall not be less than 15 feet and it is likely not to exceed 35 feet when the depth of liquefaction is considered as 50 feet, and the entire soil profile consists of liquefiable sand.

The performance criteria for liquefaction mitigation, established during the initial investigation, shall be in the form of a minimum and average penetration-resistance value associated with a soil type (fines content, clay fraction, USCS classification, CPT soil behavior type index Ic, normalized CPT friction ratio), or a tolerable liquefaction settlement as calculated by procedures discussed earlier. The choice of mitigation methods will depend on the extent of liquefaction and the related consequences. In general, options for mitigations are divided into two categories: ground improvement options and structural options.

10.B.2.5 Ground Improvement Options

Refer to Section 10.8.5.5 of the *Geotechnical* chapter.

10.B.2.6 Structural Options

Structural mitigation involves designing the structure to withstand the forces and displacements that result from liquefaction. In some cases, structural mitigation for liquefaction effects may be more economical than soil improvement mitigation methods. However,

structural mitigation may have little or no effect on the soil itself and may not reduce the potential for liquefaction. With structural mitigation, liquefaction and related ground deformations will still occur. The structural mitigation shall be designed to produce acceptable structural performance (consistent with the requirements for the two design earthquakes) in terms of liquefaction/lateral spread-induced displacements and structural damage. The appropriate means of structural mitigation may depend on the magnitude and type of liquefaction-induced soil deformation or load.

Depending on the type of structure and amount and extent of liquefaction, common structural options to be considered are as follows:

- Piles or caissons extending to non-liquefiable soil or bedrock below the potentially liquefiable soils
- Post-tensioned slab foundation (appropriate only for small, lightly loaded structures)
- Continuous spread footings having isolated footings interconnected with grade beams
- Mat foundation (appropriate only for small, lightly loaded structures)

Details, applicability, and limitations of these techniques can be found in Martin and Lew (1999). Additional requirements for design of piles in liquefied soil are presented in Section 10B.2.7.

10.B.2.7 Seismic Considerations for Lateral Design of Piles in Liquefiable Soils

Seismic considerations for lateral design of pile/shaft design in soils include the effects of liquefaction on the lateral response of piles/shafts and designing for the additional loads due to lateral spread and/or slope failures. Effects of liquefiable soils shall be included in the lateral analysis of piles/shafts by using appropriate p-y curves to represent liquefiable soils. Liquefied soil p-y curves shall be estimated using the static API sand model reduced by a p-multiplier using the method of Brandenberg, et al. (2007) and Boulanger, et al. (2007).

The displacement-based approach for evaluating the impact of liquefaction-induced lateral spreading loads on deep foundation systems that shall follow Caltrans' "Guidelines on Foundation Loading and Deformation Due to Liquefaction Induced Lateral Spreading," dated February 2011 shall be used. However, the liquefaction susceptibility and triggering analyses performed as part of this procedure shall be based on Section 10B.2.1 and Section 10B.2.2, respectively. Similarly, the lateral spread estimates shall be based on Section 10B.2.3. The Geotechnical Designer shall compare the estimated lateral spread values with the allowable deformation values and develop mitigation plans described in Section 10B.2.4, if necessary. The Geotechnical Designer shall also consider the long-term, post-construction performance requirements for earth-and-fill conditions.

Numerical methods incorporating finite element and/or finite difference techniques may be used to assess pile response in laterally spreading soils.

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10.B.2.8 Seismic Settlement of Unsaturated Soils

Seismically induced settlement of unsaturated granular soils (dry sands) shall be estimated using procedures provided by Tokimatsu and Seed (1987). Estimated values in terms of total and differential settlements shall be reported.

The Geotechnical Designer shall compare the estimated settlement values with the allowable deformation values and develop mitigation plans described in Section 10B.2.4, if necessary. The Geotechnical Designer shall also consider the long-term, post-construction performance requirements for earth-and-fill conditions.

10.B.2.9 Seismic Slope Stability and Deformation Analyses

Instability of slopes during seismic loading could be due to liquefaction or due to inertial loading, or a combination of both. In this section, instability of both the natural existing slopes and embankment slopes is addressed.

The Geotechnical Designer shall compare the estimated deformation values with the allowable deformation values and develop mitigation plans described in Section 10B.2.4, if necessary. The Geotechnical Designer shall also consider the long-term, post-construction performance requirements for earth-and-fill conditions.

10.B.2.9.1 Liquefaction-Induced Flow Failure

Liquefaction leading to catastrophic flow failures driven by static shearing stresses that result in large deformation or flow shall also be addressed by the Geotechnical Designer. These flow failures may occur near the end of strong shaking or shortly after shaking and shall be evaluated using conventional limit equilibrium static slope stability analyses. The analysis shall use residual undrained shear strength parameters for the liquefied soil assuming seismic coefficient to be zero (i.e., performed with K_h and K_v equal to zero). The residual strength parameters estimated using the method presented in Section 10B.2.2.3 shall be used. In addition, strength reduction due to cyclic degradation versus strength increase due to the effects of rate of loading shall be considered for normally consolidated clayey layers and non-liquefiable sandy layers. Chen et al. (2006) have discussed the effects of different factors on the dynamic strength of soils. The analysis shall look for both circular and wedge failure surfaces. If the limit equilibrium FOS is less than 1.1, flow failure shall be considered likely. Liquefaction flow failure deformation is usually too large to be acceptable for design of structures, and some form of mitigation will likely be needed. However, structural mitigation may be acceptable if the liquefied material and any overlying crust flow past the structure and the structure and its foundation system can resist the imposed loads.

If the FOS for this decoupled analysis is greater than 1.1 for liquefied conditions, k_y shall be estimated using pseudo-static slope stability analysis. The same strength parameters as used during the flow failure analysis shall be used. A new critical failure plane shall be searched assuming both circular and non-circular failure surfaces. Yield acceleration is defined as the

minimum horizontal acceleration in a pseudo-static analysis for which FOS is 1.0. Using the estimated k_y values, deformations shall be estimated using simplified methods such as Makdisi and Seed (1978) and Bray and Travasarou (2007). Other methods such as Newmark time history method or more advanced methods involving numerical analysis may be used, but shall be checked against the simplified methods.

For pseudo-static analyses to estimate ky values, residual strengths for the liquefied layers and reduced strengths for normally consolidated clayey and saturated sandy layers with excess pore water pressure generation (as described earlier) shall be used. This is generally a conservative approach but is appropriate for initial engineering design. For final design more advanced methods involving numerical analyses may be used to better characterize the initiation of liquefaction and pore pressure generation and subsequent reduction in strength.

10.B.2.9.2 Slope Instability Due to Inertial Effects

Pseudo-static slope stability analyses shall be used to evaluate the seismic stability of slopes and embankments due to inertial effects. The pseudo-static analysis consists of conventional limit equilibrium slope stability analysis with horizontal seismic coefficient (K_h) that acts upon the critical failure mass. A horizontal seismic coefficient (K_h) estimated using Bray and Travasarou (2009) and a vertical seismic coefficient, K_v, equal to zero shall be used for the evaluation of seismic slope stability. The Bray and Travasarou (2009) method requires an estimate of allowable deformation to compute K_h. Therefore, the allowable deformation set forth in the *Geotechnical* chapter shall be used. For these conditions, the minimum required FOS is 1.0. Alternately, pseudo-static analyses may be performed to estimate K_y values. A new failure plane shall be searched for the pseudo-static analysis. The analysis shall look for both circular and non-circular failure surfaces.

10.B.2.10 Seismic Slope Deformations

Deformation analyses shall be performed where an estimate of the magnitude of seismically induced slope deformation is required, and the pseudo-static slope stability FOS is less than 1.0. Acceptable methods of estimating the magnitude of seismically induced slope deformation include Newmark sliding block (time history) analysis, simplified displacement charts and equations based on Newmark-type analyses Makdisi and Seed (1978), Bray and Travasarou (2007), and Rathje and Saygili (2008), or dynamic stress-deformation models. These methods shall not be employed to estimate displacements if the post-earthquake static slope stability FOS using residual strengths is less than 1.0, since the slope will be unstable against static gravity loading and large displacements would be expected.

10.B.2.11 Downdrag Loading (Dragload) on Structures Due to Seismic Settlement

Downdrag loads on foundations shall be evaluated in accordance with Article 3.11.8 of the AASHTO LRFD Bridge Design Specifications and as specified herein. The AASHTO LRFD Bridge Design Specifications, Article 3.11.8, recommends the use of the non-liquefied skin

friction in the non-liquefied layers above and between the liquefied zone(s), and a skin friction value as low as the residual strength within the soil layers that do liquefy, to calculate downdrag loads for the extreme event limit state.

10.B.3 References

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Appendix 10.C: Guidelines for Rock Slope Engineering

10.C.1 Purpose

These guidelines convey a minimum standard of care for performance of rock slope engineering design, mapping, and construction.

10.C.2 Design

Rock slopes are typically composed of heterogeneous rock masses with structural anisotropic systems of relatively regular discontinuities in the form of joint sets, bedding, fissures, or foliation. The strength and slope stability of these types of rock masses are typically controlled by the discontinuities. Analytical techniques for rock slope stability assessment shall consider the kinematic stability of blocks or groups of blocks sliding upon the discontinuities, toppling, or in terms of wedge failure. Limit equilibrium methods that calculate a factor of safety shall be used. These analyses shall consider blocks that are kinematically permissible as evaluated by the Markland (1972) method, block theory (Goodman and Shi 1985), or rock slope engineering techniques described by Hoek and Bray (1981) and Wyllie and Mah (2004). If computer software is used for rock slope stability analyses, it shall be well validated and widely accepted.

For rock mass consisting of homogeneous and isotropic rock masses with irregular and/or closely spaced discontinuities that do not have well defined systematic planes of weakness, the evaluation of the stability of these types of slopes shall be based on the non-circular limit equilibrium techniques described above for soil, except that a suitable rock strength model shall be used such as General Hoek-Brown criterion (Hoek et al. 2002; Wyllie & Mah, 2004; Hoek, 2010).

Where rock slopes existing upslope of HST facilities and have the potential to shed rock pieces over time, an evaluation of the rock fall hazard shall be performed in accordance with the procedures outlined in the FHWA and Oregon DOT (2001) Rockfall Catchment Area Design Guide. Computer programs that model rockfall physics such as the Colorado Rockfall Simulation Program (CRSP III) or RocFall (by RocScience), or other equivalent software, may be used in conjunction with the FWHA procedures. Rockfall catchment basin width and inclination shall be designed to retain 99 percent of fallen rocks. If right-of-way is not available to size catchment basins to achieve 99 percent rockfall retention, additional mitigation measures such as rockfall protection walls, wire mesh, cable drape, or catchment fences shall be used in the design. In areas where rock fall is a critical problem, a railway slide fence with electronic warning system shall be installed in conjunction with an appropriate catchment ditch and rock fall retention system described above. Other warning systems for rockfall events that may be considered are as follows:

- Acoustic sensing
- Electromagnetic sensing

- Seismic sensing
- Visual sensing, using cameras

Input data and parameters used in rock slope stability analyses shall take into consideration geology, groundwater and rainfall, and proposed geometry/topography. Rock engineering parameters shall be developed for use in slope stability analyses.

When available, empirical or historical data and direct observation within the geologic unit or the past performance of similar slopes shall be considered in slope stability evaluations. In particular, when assessing existing landslides, shear strength parameters back-calculated from previous failures shall be considered.

Drained shear strength parameters shall be selected, depending upon the rate of loading, and permeability characteristics of the rock. In the analysis of existing landslides, residual shear strengths shall be used for existing landslide slip planes. FHWA (2005) Section 4 should be consulted for additional guidance on the selection of shear strength parameters.

10.C.3 Rock Slope Mapping and Condition Survey Requirements

The results of the mapping and condition surveys shall be used by the Geotechnical Designer to develop design and construction recommendations for treatment of exposed rock slopes and design of new rock cut slopes.

Under supervision of the Geotechnical Designer, qualified personnel trained in geology or engineering geology shall supervise and perform the rock slope mapping activities and data collection. A Certified Engineering Geologist (CEG) licensed in the State of California with at least 5 years of experience in rock slope design shall conduct slope condition surveys and rock mapping. Prior to mapping, the CEG shall be familiar with the local and regional geology. The mapping teams shall be knowledgeable of the rock units and structural and historical geologic aspects of the areas to be mapped.

10.C.4 Rock Slope Mapping

Procedures for mapping shall follow those given in the Rock Slopes Reference Manual, FHWA-HI-99-007, 1998, "Appendix I, Geologic Mapping," Parts 1, 2, and 3. At each mapping window, the CEG shall prepare a detailed section of the exposed cut.

Field observation data shall be recorded on approved forms similar to the one depicted on Figure AI-9a and b of the Rock Slope Reference Manual, FHWA-HI-99-007 and in field notebooks. Parameters described in the Rock Slope Reference Manual, FHWA-HI-99-007 (pages AI-3 to AI-14) shall be recorded. The following methods/assessments shall be used in the rock slope mapping:

- Use Project stationing to describe the location of rock mapping or rock slope condition observations. Record observation locations to within plus or minus 3 feet of actual Project

stations. Also, designate observation locations with a sequential numbering system. Orientation data shall be referenced to Project north (as shown on the plans).

- Color digital photographs shall be taken of each mapping area and window. A scale shall be included in the window mapping photograph. Photographs shall be mounted on an 8 1/2 x 11-inch sheet and labeled.
- Feature specific photographs shall be taken, with a minimum of one photograph per window, and labeled.
- After the geologic mapping for a window has been completed, evaluate the rock slope at each mapping window using the Rock Slope Hazard Rating System presented in Chapter 10 of the Rock Slope Reference Manual.

10.C.5 Rock Excavation

Rock excavation surfaces shall be mapped to ensure that the final excavation surfaces are examined and to aid in the discovery of unanticipated adverse geologic conditions. The mapping shall serve as a permanent record of the geologic conditions encountered during construction.

For rocks that are prone to weathering and deterioration when exposed by excavation processes, the Geotechnical Designer in collaboration with the CEG shall develop measures to protect the rock surfaces to preserve the strength and character of the material.

Rock excavation may be done either by mechanical equipment; by using explosives in drill-and-blast operations, or both. However, blasting shall not be allowed in urban areas unless otherwise permitted per local building ordinances. If permitted, blasting of rock shall be undertaken by controlled blasting techniques (cushion [trim], pre-splitting, smooth-wall blasting, and line drilling). The Geotechnical Designer in collaboration with the CEG shall select the rock excavation method to minimize vibration, over-breaks, fly rock and air blast. The Contractor shall repair any blast and vibration induced damage.

10.C.5.1 Quality Assurance During Blasting Operation

The Geotechnical Designer in collaboration with the CEG shall do the following:

- Obtain copies of applicable codes, standards, regulations, and ordinances, and keep readily accessible copies at the project field office at times.
- Retain a blasting specialist who shall be responsible for supervision of field blasting operations and personnel, and have a minimum 15 years of blasting experience with 10 years experience in responsible charge of blasting operations. Such a blasting specialist shall possess required federal, state and local licenses and/or permits.

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- Prepare a blasting plan for the areas to be excavated by means of controlled blasting. The plan shall describe the necessary items to excavate the rock using the controlled blasting techniques selected by the Geotechnical Designer.
- The Blasting Plan shall be prepared and signed by the blasting specialist.

10.C.5.2 Damage Repair

Damage to existing structures or property caused by the blasting shall be repaired by the Contractor.

The Geotechnical Designer shall notify the Authority immediately of any blasting-induced damage.

10.C.5.3 Fly Rock Control

The Contractor shall control fly rock at all times during construction.

10.C.5.4 Notification

The Contractor shall notify each adjoining property owner, the Authority, local agencies where applicable, in writing, prior to each blast. Indicate the date and time of the proposed blast, and include any safety precautions required of the adjoining property owner.

10.C.5.5 Photography

Photographs shall be taken before, during, and at the end of construction of excavated surfaces. Photos shall be properly labeled with date, subject, direction of view, vantage point, and photographer.

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Chapter 11

Seismic

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Revision	Date	Description
0	13 Mar 12	Initial Release, R0
0.1	07 Dec 2012	Addendum 7- CP01

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Acronyms

ASCE	American Society of Civil Engineers
Caltrans	California Department of Transportation
CBC	California Building Code
CBDM	Caltrans Bridge Design Manual
CQC	Complete quadratic combination
CSDC	Caltrans Seismic Design Criteria
D/C	Demand/Capacity
ELTHA	Equivalent linear time history analysis
ESA	Equivalent static analysis
HST	High-Speed Train
LDP	Linear Dynamic Procedure
MCE	Maximum Considered Earthquake
NCL	No Collapse Performance Level
NDP	Non-linear Dynamic Procedure
NSP	Non-linear Static Procedure
NLTHA	Non-linear time history analysis
OBE	Operating Basis Earthquake
OPL	Operability Performance Level
RSA	Response Spectrum Analysis
SDAP	Seismic Design and Analysis Plan
SRSS	Square root of the sum of the squares
SSI	Soil-structure interaction

11 Seismic

11.1 Scope

This chapter provides seismic design criteria for Primary Type 1, Primary Type 2, and Secondary elements of infrastructure, as defined in Section 11.4.1.

For seismic design criteria for tunnels and underground structures, see the *Geotechnical* chapter.

For seismic design criteria for earthen or soil supporting structures, such as retaining walls, embankments, cut and existing slopes, and reinforced earth structure, see the *Geotechnical* chapter.

11.2 Regulations, Codes, Standards, and Guidelines

Refer to the *General* chapter for requirements pertaining to regulations, codes, and standards. The provisions within this chapter shall govern the design. Provisions in the following current document versions shall also be considered as guidelines when sufficient criteria are not provided by this chapter.

- American Concrete Institute (ACI), Building Code Requirements for Reinforced Concrete, ACI 318
- American Welding Society (AWS) Codes
  - AWS D1.1/D1.1M: Structural Welding Code-Steel
  - AWS D1.8/D1.8M: Structural Welding Code-Seismic Supplement
- American Association of State Highway and Transportation Officials (AASHTO)/AWS D1.5M/D1.5: Bridge Welding Code
- American Association of State Highway and Transportation Officials (AASHTO), Guide Specifications for Seismic Isolation Design
- American Association of State Highway and Transportation Officials (AASHTO), Guide Specifications for LRFD Seismic Bridge Design
- California Building Code (CBC)
- American Institute of Steel Construction (AISC), Manual of Steel Construction
- American Railway Engineering and Maintenance-of-Way Association (AREMA) Manual for Railway Engineering
- American Society of Civil Engineers (ASCE) 41: Seismic Rehabilitation of Existing Structures
- California Department of Transportation (Caltrans) Bridge Design Manuals (CDBM)

- Caltrans Bridge Design Specification (CBDS): American Association of State Highway and Transportation Officials (AASHTO) LRFD Bridge Design Specifications, with California Amendments.
- Caltrans Bridge Memo to Designers Manual (CMTD)
- Caltrans Bridge Design Practices Manual (CBPD)
- Caltrans Bridge Design Aids Manual (CBDA)
- Caltrans Bridge Design Details Manual (CBDD)
- Caltrans Standard Specifications
- Caltrans Standard Plans
- Caltrans Seismic Design Criteria (CSDC)

11.3 Seismic Design and Analysis Plan

The Designer shall develop a Seismic Design and Analysis Plan (SDAP) for the element of infrastructure.

The SDAP shall define:

- the General Classification as Primary (Type 1 or Type 2), or Secondary, as defined in Section 11.4.1
- the Technical Classification as Complex, Standard, or Non-Standard, as defined in Section 11.4.2

The SDAP shall contain detailed commentary on seismic analysis for each design earthquake, indicating the analysis software to be used, and the modeling assumptions and techniques to be employed.

The SDAP shall contain commentary as to the suitability of linear versus nonlinear analysis, considering geo-hazards, the severity of design ground motions, induced strains in the soil and structure, expected nonlinearities, and expected inelastic behavior.

The SDAP shall define the pre-determined mechanism for seismic response (i.e.: plastic hinging, foundation rocking, etc.) and the regions of targeted inelastic response.

Seismic related design variances shall be submitted per the *General* chapter. The SDAP shall justify all seismic related design variances. For retrofit of existing structures, the SDAP shall provide a detailed discussion of the extent of retrofit and the proposed methodology to verify seismic performance. The required amount of retrofit will be determined by the Contracting Officer on a case by case basis.

If energy dissipation, seismic response modification, or base isolation systems are proposed, then a design variance shall be submitted per the *General* chapter. The SDAP shall discuss in detail the proposed use of any such system, including the nonlinear response, and the capacity

under service (i.e., braking and acceleration, wind, etc.) loads and OBE events in order to meet criteria in the Track-Structure Interaction section of the *Structures* chapter.

11.4 Design Classifications

Elements of HST infrastructure will provide a broad range of functions for the HST system.

General and technical classification provides a method to differentiate between seismic design objectives for the various elements of HST infrastructure.

11.4.1 General Classifications

Elements of HST infrastructure, based on their importance to HST service, shall be generally classified as Primary Type 1, Primary Type 2, or Secondary.

<u>Primary Type 1</u> – Primary Type 1 elements are those that <u>directly support HST track</u>, including, but not limited, to:

- Bridges, aerial structures, and grade separations that directly support HST track.
- Tunnels and underground structures that directly support HST track.
- Passenger stations and building structures that directly support HST track.
- Earthen or soil supporting structures, such as retaining walls, embankments, cut and existing slopes, and reinforced earth structure, that directly support HST track.

For additional seismic design criteria for Primary Type 1 elements, see the Track-Structure Interaction section of the *Structures* chapter.

<u>Primary Type 2</u> – Primary Type 2 elements are those that do not directly support HST track, but have the potential to affect HST service, including, but not limited, to:

- Highway, roadway, freight, and pedestrian structures that span over HST track.
- Train control, traction power, communication, operation, control, and equipment facilities essential for HST service.
- Tunnels and underground structures near HST track, where potential damage could affect HST service
- Building structures near HST track, where potential damage could affect HST service.
- Earthen or soil supporting structures near HST track or facilities, such as retaining walls, embankments, cut and existing slopes, and reinforced earth structure, where potential damage could affect HST track or service.
- Structures or improvements not supporting HST track, but essential for HST service, including, but not limited, to:
  - Train control, communication and operation facilities

- Traction power facilities
- Other equipment facilities essential for HST service

Secondary – Secondary elements are those not designated as Primary Type 1 or Type 2, including, but not limited to:

- Highway, roadway, freight, and pedestrian structures that do not support or span over HST track, where potential damage would not affect HST service.
- Tunnels and underground structures removed from HST track, where potential damage would not affect HST service.
- Building structures removed from HST track, where potential damage would not affect HST service, including, but not limited to:
  - Administrative buildings
  - Shop and maintenance buildings
  - Storage facilities
  - Parking structures
  - Training facilities
  - Other buildings or facilities not essential for HST service.
- Earthen or soil supporting structures removed from HST track, such as retaining walls, embankments, cut and existing slopes, and reinforced earth structure, where potential damage would not affect HST track.

Secondary structures owned by the Authority shall be subject to the seismic criteria in this chapter.

Secondary structures owned by Third Parties outside of HST right-of-way shall be subject to the applicable Third Party seismic criteria. Secondary structures owned by Third Parties within HST right-of-way shall be subject to the applicable Third Party seismic criteria and the seismic criteria in this chapter, whichever governs.

11.4.2 Technical Classification

Structures shall be technically classified, in order to determine the scope of seismic design requirements.

Complex Structures – Structures that have complex response during seismic events are considered Complex. Complex structural features include:

- Irregular Geometry – Structures that include multiple superstructure levels, variable width or bifurcating superstructures, tight horizontal curves (inside radius of curvature < 400 ft),

large subtended horizontal angles (angle > 30°), or adjacent frames with corresponding transverse or longitudinal fundamental periods of vibration varying by greater than 25%.

- Unusual Framing – Structures with straddle, outrigger, or C-bent supports, or unbalanced mass and/or stiffness distribution.
- Short Columns – Structures with concrete columns having a ratio of height to least cross sectional dimension (H/D) less than 2.5.
- Tall Columns – Structures with concrete columns having a ratio of height to least cross sectional dimension (H/D) > 10 in single curvature, or > 15 in double curvature.
- Long Span Structures – Structures that have spans greater than 300 feet.
- Skewed Structures – Structures with skewed bents or abutments > 15 degrees.
- Lightweight Concrete – Structures that consist of lightweight concrete. Lightweight concrete shall not be used for ductile earthquake resisting elements.
- Energy Dissipation, Seismic Modification, or Base Isolation Devices – Structures using energy dissipation, seismic response modification, or base isolation devices.
- Unusual Foundation Systems – Structures with foundations other than spread footings, caissons, piles, or drilled shafts.
- Unusual Geologic Conditions – Structures that are subject to unusual geologic conditions, including geologic hazards as defined within the Geotechnical Reports required by the *Geotechnical* chapter, including, but not limited, to:
  - Soft, collapsible, or expansive soils
  - Soil having moderate to high liquefaction and other seismically induced ground deformation potential
  - Soil of significantly varying type over the length of the structure
- Tunnels or Underground Structures
- Structures at or in Close Proximity to Active Faults – See the *Geotechnical* chapter for Active Fault definition.

<u>Standard Structures</u> – Structures that are not Complex Structures and comply with pending CHSTP Design Guidelines for Standard Aerial Structures.

<u>Non-Standard Structures</u> – Structures that are not Complex or Standard Structures.

11.5 Seismic Design Approach

The goal of these criteria is to safeguard against loss of life and major failures due to Maximum Considered Earthquake (MCE), and interruption of HST operations due to structural or track damage and derailment caused by Operating Basis Earthquake (OBE).

11.5.1 Seismic Performance Criteria

Two levels of seismic performance criteria are defined:

- No Collapse Performance Level (NCL) – For the NCL, Table 11-1 states the performance objectives and acceptable damage for Maximum Considered Earthquake (MCE) design.

Table 11-1: Performance Objectives/Acceptable Damage for NCL

<table>
<tr><th>Performance Level & Design Earthquake</th><th>Performance Objectives</th><th>Acceptable Damage</th></tr>
<tr><td rowspan="4">No Collapse Performance Level (NCL)

Maximum Considered Earthquake (MCE)</td><td rowspan="4"><u>Primary Type 1</u>
• No structural collapse.
• Occupants not on trains shall be able to evacuate the structure safely.
• Damage and collapse due to train derailment shall be mitigated through containment design.
• If derailment occurs, train passengers and operators shall be able to be evacuated from derailed trains safely.
• Reliable access for post-earthquake emergency services shall be provided for within design.
• Extensive repairs or complete replacement of some system components may be required before train operation may resume.
• For underground structures, no flooding or mud inflow.

<u>Primary Type 2</u>
• No structural collapse.
• Occupants shall be able to evacuate the structure safely.
• Damage and collapse due to train derailment shall be mitigated through containment design.
• Reliable access for post-earthquake emergency services shall be provided for within design.
• Extensive repairs or complete replacement of some system components may be required before train operation may resume.
• For underground structures, no flooding or mud inflow.

<u>Secondary</u>
• No structural collapse.
• Occupants shall be able to evacuate the structure safely.
• Reliable access for post-earthquake emergency services shall be provided for within design.
• Extensive repairs or complete replacement may be required.
• For underground structures, no flooding or mud inflow.</td><td>Significant yielding of reinforcement steel or structural steel. Minor fracturing of secondary and redundant steel members or rebar, with no collapse.</td></tr>
<tr><td>Extensive cracking and spalling of concrete, with minimal loss of vertical load carrying capability.</td></tr>
<tr><td>Large permanent offsets, without collapse</td></tr>
<tr><td>Extensive damage to HST track, track support, and rail fasteners</td></tr>
</table>

- Operability Performance Level (OPL) – For the OPL, Table 11-2 states the performance objectives and acceptable damage for Operating Basis Earthquake (OBE) design.

Table 11-2: Performance Objectives/Acceptable Damage for OPL

Performance Level	Performance Objectives	Acceptable Damage
Operability Performance Level (OPL) Operating Basis Earthquake (OBE)	<u>Primary Type 1</u> • Essentially elastic structural response • Occupants not on trains shall be able to evacuate the structure safely. • No derailment, trains shall be able to safely brake from the maximum design speed to a safe stop. • Train passengers and operators shall be able to evacuate stopped trains safely. • Primary (Type 1) structure and track designed to comply with Track-Structure Interaction section of the *Structures* chapter. • Minimal disruption of service for all systems supporting HST operations. • Resumption of HST operations within a few hours with the possibility of reduced speeds. • For underground structures, no flooding or mud inflow <u>Primary Type 2</u> • Essentially elastic structural response • Occupants shall be able to evacuate the structure safely. • Minimal disruption of service for all systems supporting HST operations. • Resumption of HST operations within a few hours with the possibility of reduced speeds. • For underground structures, no flooding or mud inflow <u>Secondary</u> • OPL does not apply	Minor inelastic behavior, no spalling. No damage to HST track, track support, and rail fasteners Negligible permanent deformation of substructure and superstructure components.

11.5.2 Design Earthquakes

For design, two design earthquakes, the Maximum Considered Earthquake (MCE) and the Operating Basis Earthquake (OBE), are defined:

- Maximum Considered Earthquake – Ground motions corresponding to greater of (1) a probabilistic spectrum based upon a 10% probability of exceedance in 100 years (i.e., a return period of 950 years); and (2) a deterministic spectrum based upon the largest median response resulting from the maximum rupture (corresponding to M_{max}) of any fault in the vicinity of the structure.
- Operating Basis Earthquake – Ground motions corresponding to a probabilistic spectrum based upon an 86% probability of exceedance in 100 years (i.e., a return period of 50 years).

11.5.3 Retrofit of Existing Structures

See the *Structures* chapter for requirements for Primary Type 2 or Secondary structures not supporting HST, which addresses retrofit of existing structures.

Existing Primary Type 2 structures shall be subject to both NCL/MCE and OPL/OBE design. Existing Secondary structures shall be subject to NCL/MCE design only.

A detailed discussion on the retrofit of existing structures shall be defined in the SDAP, as discussed in Section 11.3.

11.5.4 Seismic Requirements for Temporary Construction Structures

Temporary construction structures include new temporary structures and the temporary shoring and underpinning of existing structures.

For seismic requirements for temporary construction structures, the following design spectra and motions:

- 125% of the OBE design spectra and motions, or
- a scaled OBE spectra where the peak ground acceleration (PGA) equals 0.1g

whichever governs, shall apply.

For temporary construction structures, the performance requirements for NCL as given in Table 11-1 for Secondary Structures shall apply.

11.6 Seismic Design Requirements

For each general classification, Table 11-3 defines seismic design requirements for each seismic performance level and design earthquake.

Note that for Primary Type 1 generally classified structures, TSI/OBE refers to track and structure seismic performance during OBE events as defined in Track-Structure Interaction section of the *Structures* chapter.

Table 11-3: Seismic Design Requirements

General Classification		
Primary Type 1	**Primary Type 2**	**Secondary**
NCL/MCE	NCL/MCE	NCL/MCE
OPL/OBE	OPL/OBE	--
TSI/OBE	--	--

11.7 Bridges, Aerial Structures, and Grade Separations

All Primary Type 1 or Type 2 bridges, aerial structures, and grade separations shall be subject to both NCL/MCE and OPL/OBE seismic criteria herein.

All Secondary bridges, aerial structures, and grade separations owned by the Authority shall be subject to the NCL/MCE seismic criteria herein.

All Secondary bridges, aerial structures, and grade separations owned by Third Parties shall be subject to the applicable Third Party seismic criteria.

11.7.1 Design Codes

For NCL/MCE design, current Caltrans performance based design methods as given in CBDM form the basis of design. Certain criteria herein exceed those of CBDM. For items not specifically addressed in this or other Design Criteria chapters, CBDM shall be used. See the *Structures* chapter for the load combination including MCE events.

For OPL/OBE design, current Caltrans force based design methods as given in AASHTO LRFD with Caltrans Amendments form the basis of design. Certain criteria herein exceed those of AASHTO LRFD with Caltrans Amendments. See the *Structures* chapter for the load combinations including OBE events.

Table 11-4 summarizes the applicable seismic design code for each General Classification.

Table 11-4: Applicable Bridge, Aerial Structure and Grade Separation Design Codes

Performance/ Design Earthquake	General Classification		
	Primary Type 1	Primary Type 2	Secondary
NCL/MCE	CBDM	CBDM	CBDM
OPL/OBE	AASHTO/Caltrans	AASHTO/Caltrans	--
TSI/OBE	*Structures* chapter	--	--

11.7.2 Seismic Design Approach

The seismic design approach differs depending upon the design earthquake.

11.7.2.1 NCL/MCE Design Approach

For NCL/MCE design, the approach shall be:

- The structure shall have a clearly defined and pre-determined mechanism for seismic response, with targeted regions for inelastic response.
- Inelastic behavior shall be limited to columns, piers, and abutments, at above soil or water surface locations.

- Regions adjacent to inelastic behavior shall be capacity protected and perform as essentially elastic.
- Seismic design and detailing requirements per CSDC shall be satisfied.

Allowable pre-determined mechanisms for NCL/MCE design include:

- Flexural Plastic Hinging
- Foundation Rocking (see Section 11.7.2.1)
- Energy dissipation, seismic response modification, or base isolation systems

A. Flexural Plastic Hinging

Flexural plastic hinging shall be limited to the columns or piers. The location of plastic hinges shall be at above soil or water surface locations accessible for inspection and repair.

Non-fusing or capacity protected members shall be designed to prevent brittle failure mechanisms, such as footing shear, joint shear, column shear, tensile failure at the top of concrete footings, and unseating of girders. Non-fusing or capacity protected members shall be designed as essentially elastic, with 120% over-strength factor on the column plastic moment and shear applied.

Modeling, analysis and design shall conform to CBDM and CSDC.

For exceptionally soft soil sites, if below ground plastic hinging is unavoidable in caissons, piles or drilled shafts, then a design variance shall be submitted per the *General* chapter. All seismic related design variances shall be identified and justified in the SDAP, as required in Section 11.3.

B. Foundation Rocking

Foundation rocking shall not be allowed for Primary Type 1, or Complex structures.

Stable foundation rocking shall be allowed for NCL/MCE and OPL/OBE design for:

- Primary Type 2 or Secondary, and Standard or Non-Standard structures
- No skew
- Single column piers or multiple column bents, where most of the structural mass is concentrated at a single level.

In absence of rocking, Equivalent Static Analysis (ESA) as defined in Section 11.7.3.15 would apply to the structure.

See Section 11.7.3.16 for foundation rocking methodology.

11.7.2.2 OPL/OBE Design Approach

For OPL/OBE design, the approach shall be:

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- The structure shall respond as essentially elastic.
- For Primary Type 1 structures, the structure and track seismic performance during OBE events shall comply with the Track-Structure Interaction section of the Structures chapter.
- Foundation Rocking (see Section 11.7.2.1)

OPL/OBE demands shall be compared versus force-based capacities calculated per AASHTO LRFD with Caltrans Amendments per Section 11.7.5.3.

11.7.2.3 Energy Dissipation, Seismic Response Modification, or Base Isolation Systems

Energy dissipation, seismic response modification, or base isolation systems can be used to minimize damage, reduce seismic demands on substructures, and reduce foundation costs.

For seismic isolation design, CBDS implemented AASHTO's Guide Specifications for Seismic Isolation Design shall apply.

Energy dissipation, seismic response modification, or base isolation systems shall contain sufficient capacity under service (i.e., braking and acceleration, wind, etc.) loads and OBE events, in order to meet criteria in the Track-Structure Interaction section of the *Structures* chapter.

If energy dissipation, seismic response modification, or base isolation systems are proposed, then the use of such systems shall be identified in the SDAP, as required in Section 11.3.

11.7.3 Seismic Demands on Structural Components

In increasing order of complexity, analysis techniques include equivalent static analysis (ESA), response spectrum analysis (RSA), equivalent linear time history analysis (ELTHA), and nonlinear time history analysis (NLTHA).

For NCL/MCE design of Complex structures, NLTHA shall apply. For NCL/MCE design of Standard or Non-Standard structures, the appropriate analysis technique will depend upon the site specifics and structure.

For OPL/OBE design of the structure, a linear elastic analysis technique may be used. For Primary Type 1 structures, due to non-linear rail fastener slippage during OBE events (see the Track-Structure Interaction section of the *Structures* chapter), NLTHA shall apply.

11.7.3.1 Force Demands (F_U) for OPL/OBE

For OPL/OBE design, the ultimate force demand, F_u, shall be determined for all structural components.

For the structure, the loading combination shall be as specified in the *Structures* chapter.

For Primary Type 1 structures, the loading combinations for structure and track seismic demands during OBE events shall be as specified in the Track-Structure Interaction section of the *Structures* chapter

11.7.3.2 Displacement Demands (Δ_D) for NCL/MCE

For NCL/MCE design, the global or local displacement demand, Δ_D, at the center of mass of the superstructure for each bent shall be determined, and compared versus the displacement capacity, Δ_C.

The loading combination shall be as specified in the *Structures* chapter.

11.7.3.3 Vertical Earthquake Motions

Where the MCE peak rock acceleration is 0.6g or greater, an equivalent static vertical load per CSDC shall be applied to the superstructure for design in order to estimate the effects of vertical acceleration.

For structures at or in close proximity to hazardous earthquake faults, as defined in the *Geotechnical* chapter, vertical motions shall be considered. This applies to the structural loading combinations as specified in the *Structures* chapter, and the loading combinations for structure and track seismic demands during OBE events as specified in the Track-Structure Interaction section of the *Structures* chapter.

11.7.3.4 Effective Sectional Properties

For NCL/MCE design, cracked bending and torsional moments of inertia for ductile substructure, and superstructure concrete members shall be per CSDC.

When moment-curvature analysis of concrete members is used, elemental cross sectional analysis shall be performed which considers the effects of concrete cracking, the degree of confinement, reinforcement yield and strain hardening, in accordance with CMTD and CSDC.

For structural steel sections, either moment-curvature analysis shall be performed which considers the stress-strain relationship of the structural steel, or effective section properties derived based upon the degree of nonlinearity shall be used. Effective section properties for structural steel components shall be consistent with CBDS and AISC Manual of Steel Construction.

For OPL/OBE design, effective bending moments of inertia for concrete column members shall consider the maximum moment demand, M_a, and the cracking moment, M_{cr}, in accordance with AASHTO LRFD with Caltrans Amendments Section 5.7.3.6.2. When using this method, the cracked moment of inertia, I_{cr}, shall be per CSDC. Alternatively, OBE effective sectional properties shall be directly found through the use of moment-curvature analysis.

11.7.3.5 Mass

Both elemental and lumped mass shall be used in analysis.

Translational and rotational elemental mass is based upon the mass density, length and cross sectional properties of discrete elements within the analytical model.

Translational and rotational lumped mass shall be based upon engineering evaluation of the structure, and consider items modeled as rigid (i.e., pile and bent caps), or items not explicitly modeled (i.e., non-structural mass).

Where applicable, train mass shall be considered per Section 11.7.3.12.

11.7.3.6 Material Properties for Demands

For NCL/MCE design, expected material properties shall be used in calculating the structural seismic demands in conformance with CSDC for concrete members and AASHTO LRFD with Caltrans Amendments for structural steel members.

For OPL/OBE design, nominal material properties shall be used in calculating the structural seismic demands.

11.7.3.7 Flexural Plastic Hinging

Where flexural plastic hinging is used as the NCL/MCE seismic response mechanism of the structure, the analysis shall conform to CSDC methods and procedures.

11.7.3.8 Assessment of Track-Structure Interaction

For assessment of train and track-structure interaction, including requirements and load combinations which include OBE events, see the Track-Structure Interaction section of the *Structures* chapter.

11.7.3.9 Foundation Stiffness

Foundation stiffness, including the effects of soil structure interaction if applicable, shall be considered for seismic analyses per the *Geotechnical* chapter.

11.7.3.10 Boundary Conditions

In cases where the structure is adjacent to or connected to other structures which are not included in the model (e.g.: adjacent spans or abutments), the model shall also contain appropriate elements at its boundaries to capture mass and stiffness effects of the adjacent structures.

For NCL/MCE abutment design, longitudinal and transverse response shall be per CSDC.

For OPL/OBE design of Primary Type 1 structures, abutment response shall be elastic.

After completion of static or dynamic analysis, a check shall be performed to verify that the boundary conditions and element properties are consistent with initial modeling assumptions.

11.7.3.11 Continuous Welded Rail

For structures that carry continuously welded rail, there may be benefits to structural performance during a seismic event provided by the rail system. The rails may serve as restrainers at the expansion joints tying adjacent frames together under seismic loading. However, this is complex behavior, which shall be substantiated and validated through analysis.

Since the rail system seismic response at the expansion joints is highly nonlinear, linear elastic analysis is not appropriate. Instead a nonlinear time-history analysis, in accordance with Section 11.7.3.19, shall be performed which considers track-structure interaction.

The Track-Structure Interaction section of the *Structures* chapter contains details of the rail-structure interaction modeling methodology. The rail-structure interaction shall include the rails and fastening system, modeled to consider fastener slippage and rail stiffness. The capacity of the fastener connections in both shear and uplift shall be accounted for in the analysis. Without these rail-structure interaction considerations, any structural performance benefits provided by continuous welded rail shall be ignored.

11.7.3.12 Train Mass and Live Load

For NCL/MCE design, train mass and live load shall not be considered.

For OPL/OBE design, train mass and live load shall be considered per load combinations defined in the *Structures* chapter. For all OBE load combinations, both strength and track-structure interaction per the *Structures* chapter, train loads may be modeled as equivalent static distributed loads, and train mass as stationary mass. Although equivalent distributed loads are used in the analysis, local design shall account for any effects due to actual concentrated axle loads.

For OBE strength load combinations, the following train effects shall be considered simultaneously:

<u>Single track structures</u>:

- One train vertical live load + impact
- One train longitudinal braking force
- Mass of 1 train, applied at the center of train mass

<u>Multiple track structures:</u>

1/2 of trains potentially occupying the structure shall be considered. Where an odd number of trains potentially occupy the structure, round down to the nearest whole number of trains (example: for 3 trains, use 1/2(3) = 1.5 and round down to 1).

- 1/2 of the trains live load + impact
- 1/2 of trains longitudinal braking force

- Mass of 1/2 of the trains, applied at the center of train mass

For OBE track-structure interaction load groups per the *Structures* chapter, the following train effects shall be considered simultaneously:

- One train vertical live load + impact
- One train longitudinal braking force, where applicable (Rail-Structure Interaction Only)
- Mass of 1 train, applied at the center of train mass

11.7.3.13 P-Δ Effects

For flexural plastic hinging, P-Δ effects shall be considered and conform to the requirements in CSDC.

For foundation rocking response, P-Δ effects shall be considered as per Section 11.7.3.16.

11.7.3.14 Displacement Demand Amplification Factor

When ESA or RSA is used for NCL/MCE or OPL/OBE design, the displacement demand, Δ_D, obtained shall be multiplied by an amplification factor, C, as follows:

For $T_i/T_o < 1$: $C = [0.8/ (T/T_o)] + 0.2$

For $T_i/T_o > 1$: $C = 1.0$

Where:

T_i = fundamental period of structure in the longitudinal or transverse direction (including foundation stiffness)

T_o = the period centered on the peak of the longitudinal or transverse acceleration response spectrum

This amplification factor is used in order to account for the uncertainty associated with the calculation of structural period for stiff structures. This amplification factor shall not apply to foundation rocking analysis.

11.7.3.15 Equivalent Static Analysis

Equivalent Static Analysis (ESA) may be used to determine earthquake demands, E:

- For NCL/MCE design, the Displacement Demand, Δ_D, at the center of mass of the superstructure.
- For OPL/OBE design, the Force Demands, F_u

when the structure can be characterized as a simple single-degree-of-freedom (SDOF) system, and more sophisticated dynamic analysis will not add significantly more insight into behavior.

For NCL/MCE and OPL/OBE design, ESA shall apply to Standard or Non-Standard structures with the following characteristics:

- No skew.
- Single column piers or multiple column bents where most of the structural mass is concentrated at a single level.
- The fundamental mode of vibration is uniform translation.

A simply defined lateral force distribution due to balanced spans, and approximately equal bents.ESA shall not apply to Complex structures.

ESA earthquake demands shall be determined from horizontal spectra by either of 2 methods:

- Method 1 – Earthquake demand, $E = (E_L^2 + E_T^2)^{1/2}$, where E_L and E_T are the responses due to longitudinal and transverse direction earthquake motions as defined below. The application of ground motion shall be along the principal axes of individual components.
- Method 2 – Earthquake demand, E, by using the 100%-30% rule, for 2 cases:

Case 1: $E = 1.0E_L + 0.3E_T$

Case 2: $E = 0.3E_L + 1.0E_T$

For calculation of ESA earthquake demands for both Methods 1 and 2:

Longitudinal: $E_L = C * S_a^L * W$

Transverse: $E_T = C * S_a^T * W$

Where:

C	=	the amplification factor, C, given in Section 11.7.3.14
S_a^L	=	longitudinal acceleration response spectral value at period T_L
T_L	=	fundamental period of structure in the longitudinal direction (including foundation stiffness)
S_a^T	=	transverse acceleration response spectral value at period T_T
T_T	=	fundamental period of structure in the transverse direction (including foundation stiffness)
W	=	tributary dead load + superimposed dead load for NCL/MCE design
W	=	tributary dead load + superimposed dead load + train mass and live load per Section 11.7.3.12 for OPL/OBE design.

Effective sectional properties shall be used per Section 11.7.3.4. Material properties shall be used per Section 11.7.3.6.

An equivalent linear representation of foundation stiffness shall be used. Iteration shall be performed until the equivalent linear foundation stiffness converges (i.e., the assumed stiffness is consistent with the calculated response).

For both NCL/MCE and OPL/OBE design, 5% damped response spectra, as given in the Geotechnical Reports required by the *Geotechnical* chapter, shall be used to determine S_a.

11.7.3.16 Foundation Rocking

For NCL/MCE and OPL/OBE design, where foundation rocking is allowed per Section 11.7.2.1, the procedure presented in AASHTO's Guide Specifications for LRFD Seismic Bridge Design, Appendix A: Foundation-Rocking Analysis shall be used for design. Within this reference, design for P-Δ effects and column plastic hinging requirements are outlined.

For NCL/MCE design, should column plastic hinging occur concurrently with foundation rocking response, then all non-fusing or capacity protected members including the foundation, if applicable, shall be designed as essentially elastic, with 120% over-strength factor on the column plastic moment and shear applied.

When determining the rocking response, consideration shall be given to possible future conditions, such as a change in depth of the soil cover above the footing or other loads that may increase or decrease the rocking response.

The Geotechnical Reports required by the *Geotechnical* chapter shall provide information and design parameters regarding foundation rocking.

11.7.3.17 Response Spectrum Analysis

Response Spectrum Analysis (RSA) shall be used to determine earthquake demands, E:

- For NCL/MCE design, the Displacement Demand, Δ_D, at the center of mass of the superstructure
- For OPL/OBE design, the Force Demands, F_u

when ESA provides an unrealistic estimate of the dynamic behavior.

For NCL/MCE and OPL/OBE design, RSA shall apply to Standard or Non-Standard structures with the following characteristics:

- Skewed bents or abutments ≤ 15 degrees
- Single column pier or multiple column bents
- Response primarily captured by the fundamental structural mode shapes containing a minimum of 90% mass participation in the longitudinal and transverse directions

For NCL/MCE design, RSA shall not apply to Complex structures.

For OPL/OBE design, RSA may apply to Complex structures, upon approval of the SDAP per Section 11.3.

RSA involves creating a linear, three dimensional dynamic model of the structure, with appropriate representation of all material properties, structural stiffness, mass, boundary conditions, and foundation characteristics. The dynamic model is used to determine the fundamental structural mode shapes. A sufficient number of mode shapes shall be included to account for a minimum of 90% mass participation in the longitudinal and transverse directions.

Care shall be taken to ensure 90% mass participation for long aerial structure models. The Designer shall examine the mode shapes to ensure that they sufficiently capture the behavior of the structure.

A linear elastic multi-modal spectral analysis shall be performed using the 5% damped response spectra, as given in the Geotechnical Reports required by the *Geotechnical* chapter. The modal response contributions shall be combined using the complete quadratic combination (CQC) method.

For NCL/MCE design, RSA based on design spectral accelerations will likely predict forces in some elements that exceed their elastic limit, the presence of which indicates nonlinear behavior. The Designer shall recognize that forces generated by RSA could vary considerably from the actual force demands on the structure. Sources of nonlinear response not captured by RSA include the effects of surrounding soil, yielding of structural members, opening and closing of expansion joints, plastic hinging, and nonlinear restrainer and abutment behavior.

Where there is a change in soil type along the bridge alignment, consideration shall be made to the possibility that out-of-phase ground displacements at 2 adjacent piers may increase the computed demand on expansion joints, rails or columns. This effect is not explicitly considered in RSA. In such cases, more sophisticated time history analyses shall be used.

Appropriate linear stiffness shall be assumed for abutments and expansion joints per CSDC. Analyses shall be performed for compression models (abutments engaged, gaps between frames closed) and for tension models (abutments inactive, gaps between frames open), to obtain a maximum response envelope. If analysis results show that soil capacities are exceeded at an abutment, iterations shall be performed with decreasing soil spring constants at the abutment per CSDC recommendations.

For calculation of differential displacements at expansion joints and for calculation of column drift, the analysis shall either explicitly compute these demands as modal scalar values or assume that the displacements and rotations combine to produce the highest or most severe demand on the structure.

RSA demands shall be determined from horizontal spectra by either of the 2 following methods:

- Method 1 – Earthquake demand, $E = (E_L^2 + E_T^2)^{1/2}$, where E_L and E_T are the responses due to longitudinal and transverse earthquake spectra as defined below. The application of ground motion shall be along the principal axes of individual components.
- Method 2 – Earthquake demand, E, by using the 100%-30% rule, for 2 cases:

Case 1 : $E = 1.0E_L + 0.3E_T$

Case 2 : $E = 0.3E_L + 1.0E_T$

For calculation of RSA earthquake demands:

Longitudinally: E_L = C * (RSA demands from longitudinal earthquake spectra)

Transversely: E_T = C * (RSA demands from transverse earthquake spectra)

Where:

C = the amplification factor, C, given in Section 11.7.3.14

Effective sectional properties shall be used per Section 11.7.3.4. Material properties shall be used per Section 11.7.3.6.

An equivalent linear representation of foundation stiffness shall be used. Iteration shall be performed until the equivalent linear foundation stiffness converges (i.e., the assumed stiffness is consistent with the calculated response).

For NCL/MCE design, dead and superimposed dead loads shall be applied as an initial condition.

For OPL/OBE design, in addition to dead and superimposed dead loads, train mass and live load shall be considered per Section 11.7.3.12.

For NCL/MCE and OPL/OBE design, modal damping shall be 5%.

11.7.3.18 Equivalent Linear Time History Analysis

Equivalent Linear Time History Analysis (ELTHA) shall be used to determine earthquake demands, E:

- For NCL/MCE design, the Displacement Demand, Δ_D, at the center of mass of the superstructure
- For OPL/OBE design, the Force Demands, F_u

when ESA or RSA provides an unrealistic estimate of the dynamic behavior.

For NCL/MCE and OPL/OBE design, ELTHA shall apply to Standard or Non-Standard structures with the following characteristics:

- Skewed bents or abutments ≤ 15 degrees

- Single column pier or multiple column bents

For NCL/MCE design, ELTHA shall not apply to Complex structures.

For OPL/OBE design, ELTHA may apply to Complex structures, upon approval of the SDAP per Section 11.3.

ELTHA involves creating a three dimensional dynamic model of the structure, with appropriate representation of all material properties, structural stiffness, mass, boundary conditions, and foundation characteristics.

For NCL/MCE and OPL/OBE design, motions consistent with the 5% damped response spectra shall be used, as given in the Geotechnical Reports required by the *Geotechnical* chapter.

For NCL/MCE and OPL/OBE design, damping shall be 5%.

Should Rayleigh damping be used for ELTHA, it requires the calculation of both stiffness and mass proportional coefficients anchored at 2 structural frequencies, which shall envelope all important modes of structural response. The lower anchoring frequency (i.e., longest period) shall be determined using effective section properties per Section 11.7.3.4. and by reducing the resulting lowest natural frequency by 10%. The higher anchoring frequency (i.e., shortest period) shall be chosen such that a minimum of 90% mass participation in the longitudinal, transverse directions are mobilized.

Effective sectional properties shall be used per Section 11.7.3.4. Material properties shall be used per Section 11.7.3.6.

Appropriate linear stiffness shall be assumed for abutments and expansion joints per CSDC. Analyses shall be performed for compression models (abutments engaged, gaps between frames closed) and for tension models (abutments inactive, gaps between frames open), to obtain a maximum response envelope. If analysis results show that soil capacities are exceeded at an abutment, iterations shall be performed with decreasing soil spring constants at the abutment per CSDC recommendations.

An equivalent linear representation of foundation stiffness shall be used. Iteration shall be performed until the equivalent linear foundation stiffness converges (i.e., the assumed stiffness is consistent with the calculated response).

For NCL/MCE design, dead and superimposed dead loads shall be applied as an initial condition.

For OPL/OBE design, in addition to dead and superimposed dead loads, train mass and live load shall be considered per Section 11.7.3.12.

The time histories shall reflect the characteristics (fault distance, site class, moment magnitude, spectral shape, rupture directivity, rupture mechanisms, and other factors) of the controlling

design earthquake ground motions, as given in the Geotechnical Reports required by the *Geotechnical* chapter.

The motions shall consist of 2 horizontal ground motion time histories, selected, scaled, and spectrally matched. The 2 horizontal components of the design ground motions shall be representative of the fault-normal and fault-parallel motions at the site, as appropriate, and transformed considering the orientation of the motions relative to the local or global coordinate systems of the structural model.

Consideration of vertical earthquake motions shall be considered per Section 11.7.3.3.

When ELTHA is used, seven (7) sets of ground motions shall be used, and the average maximum values of each response parameter (e.g., force or strain in a member, displacement or rotation at a particular location) shall be used for design.

After completion of each ELTHA, the Designer shall verify that structural members which are modeled as elastic do remain elastic and satisfy strength requirements.

11.7.3.19 Nonlinear Time History Analysis

Nonlinear Time History Analysis (NLTHA) shall be used to determine earthquake demands, E:

- For NCL/MCE design, the Displacement Demand, Δ_D, at the center of mass of the superstructure
- For OPL/OBE design, the Force Demands, F_u

when ESA, RSA or ELTHA provides an unrealistic estimate of the dynamic behavior, provides overly conservative demands, or where nonlinear response is critical for design.

For NCL/MCE design, NLTHA shall apply to Complex structures.

For OPL/OBE design, NLTHA, ELTHA, or RSA may apply to Complex structures, upon approval of the SDAP per Section 11.3.

For TSI/OBE design of Primary Type 1 structures, due to required track and structure seismic performance during OBE events per the Track-Structure Interaction section of the *Structures* chapter, NLTHA shall be used.

NLTHA involves creating a three dimensional dynamic model of the structure, with appropriate representation of all material properties, structural stiffness, mass, boundary conditions, and foundation characteristics. This dynamic model is used to determine the dynamic characteristics of the structure by including selected nonlinear representations of structural and foundation elements.

For NCL/MCE and OPL/OBE design, motions consistent with the 5% damped response spectra shall be used, as given in the Geotechnical Reports required by the *Geotechnical* chapter.

For NCL/MCE and OPL/OBE design, damping shall be 5%.

Should Rayleigh damping be used for NLTHA, it requires the calculation of both stiffness and mass proportional coefficients anchored at 2 structural frequencies, which shall envelope all important modes of structural response. The lower anchoring frequency (i.e., longest period) shall be determined using effective section properties per Section 11.7.3.4 and by reducing the resulting lowest natural frequency by 10%. The higher anchoring frequency (i.e., shortest period) shall be chosen such that a minimum of 90% mass participation in the longitudinal, transverse directions are mobilized.

Effective sectional properties or moment-curvature analysis shall be used per Section 11.7.3.4. Material properties shall be used per Section 11.7.3.6.

If applicable, appropriate linear stiffness may be assumed for abutments and expansion joints per CSDC. Analyses shall be performed for compression models (abutments engaged, gaps between frames closed) and for tension models (abutments inactive, gaps between frames open), to obtain a maximum response envelope. If analysis results show that soil capacities are exceeded at an abutment, iterations shall be performed with decreasing soil spring constants at the abutment per CSDC recommendations. Otherwise, nonlinear representations of abutment and expansion joint characteristics shall be used.

Where applicable, an equivalent linear representation of foundation stiffness shall be used, and iteration shall be performed until the equivalent linear foundation stiffness converges (i.e., the assumed stiffness is consistent with the calculated response). Otherwise, nonlinear representations of foundation characteristics shall be used.

For NCL/MCE design, dead and superimposed dead loads shall be applied as an initial condition.

For OPL/OBE design, in addition to dead and superimposed dead loads, train mass and live load shall be considered per Section 11.7.3.12.

The time histories shall reflect the characteristics (fault distance, site class, moment magnitude, spectral shape, rupture directivity, rupture mechanisms, and other factors) of the controlling design earthquake ground motions, as given in the Geotechnical Reports required by the *Geotechnical* chapter.

The motions shall consist of 2 horizontal ground motion time histories, selected, scaled, and spectrally matched. The 2 horizontal components of the design ground motions shall be representative of the fault-normal and fault-parallel motions at the site, as appropriate, and transformed considering the orientation of the motion relative to the local or global coordinate systems of the structural model.

Consideration of vertical earthquake motions shall be considered per Section 11.7.3.3.

When NLTHA is used, seven (7) sets of ground motions shall be used, and the average maximum values of each response parameter (e.g., force or strain in a member, displacement or rotation at a particular location) shall be used for design.

After completion of each NLTHA, the Designer shall verify that structural members which are modeled as elastic do remain elastic and satisfy strength requirements.

11.7.4 Seismic Capacities of Structural Components

11.7.4.1 Force Capacities (ΦF_N) for OPL/OBE

For OPL/OBE design, LRFD force capacities, ΦF_N, for all structural components shall be found in accordance with AASHTO LRFD with Caltrans Amendments. Nominal material properties shall be used when determining OBE capacities.

11.7.4.2 Displacement Capacity (Δ_C) for NCL/MCE

For NCL/MCE design employing flexural plastic hinging using ESA, RSA, and ELTHA demands, the displacement capacity, Δ_C, shall be determined by nonlinear static pushover analysis, as described in Section 11.7.4.3. The displacement capacity shall be defined as the controlling structure displacement that occurs when any element of targeted inelastic response reaches its allowable capacity in the pushover analysis. The allowable capacity is reached when the concrete or steel strain of any element of targeted inelastic response meets the allowable strains specified in Sections 11.7.4.5 to 11.7.4.8.

If moment curvature representation of plastic hinging is used for NLTHA, then the curvature demands shall be converted to concrete or steel strains, and verified versus allowable strains specified in Sections 11.7.4.5 to 11.7.4.8.

The displacement capacity, Δ_C, shall include all displacements attributed to flexibility in the foundations, bent caps, and other elastic and inelastic member responses in the system. The assumptions made to determine the displacement capacity, Δ_C, shall be consistent with those used to determine the displacement demand, Δ_D.

All capacity protected structural members and connections shall satisfy requirements in Section 11.7.5.5.

11.7.4.3 Nonlinear Static Pushover Analysis

For NCL/MCE design employing flexural plastic hinging, the following procedure shall be followed to determine the displacement capacity, Δ_C, using nonlinear static pushover analysis.

Dead and superimposed dead load shall be applied as an initial step.

Incremental lateral displacements shall be applied to the system. A plastic hinge shall be assumed to form in an element when the internal moment reaches the idealized yield limit in accordance with Section 11.7.3.7. The sequence of plastic hinging through the frame system

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shall be tracked until an ultimate failure mode is reached. The system capacity shall then be determined in accordance with CSDC.

11.7.4.4 Plastic Hinge Rotational Capacity

Plastic moment capacity of ductile flexural members shall be calculated by moment-curvature (M-ϕ) analysis and shall conform to CSDC for concrete members and AASHTO LRFD with Caltrans Amendments for structural steel members.

The rotational capacity of any plastic hinge is defined as the product of the plastic hinge length, as defined by CSDC, and the curvature (from M-ϕ analysis) when the element of targeted inelastic response first reaches the allowable strains in Sections 11.7.4.5 to 11.7.4.8.

11.7.4.5 Strain Limits for Ductile Reinforced Concrete Members

For NCL/MCE design, the following reinforcing steel (A706/Grade 60) allowable tensile strain limits (ε_{su}^{a}) shall apply for ductile reinforced concrete members:

NCL/MCE: $\varepsilon_{su}^{a} \leq 2/3\ \varepsilon_{su}$

where: ε_{su} = ultimate tensile strain per CSDC

For NCL/MCE design, the following allowable confined concrete compressive strain limits (ε_{cu}^{a}) shall apply for ductile reinforced concrete members:

MCE: $\varepsilon_{cu}^{a} \leq \varepsilon_{cu}$

where: ε_{cu} = ultimate compressive strain as computed by Mander's model for confined concrete.

11.7.4.6 Strain Limits for Ductile Reinforced Concrete Caissons, Piles, and Drilled Shafts

For NCL/MCE design, the following reinforcing steel (A706/Grade 60) allowable tensile strain limit (ε_{su}^{a}) shall apply for ductile reinforced concrete caissons, piles, and drilled shafts:

NCL/MCE: $\varepsilon_{su}^{a} \leq \varepsilon_{sh}$

where: ε_{sh} = tensile strain at the onset of strain hardening per CSDC

For NCL/MCE design, the following allowable confined concrete compressive strain limits (ε_{cu}^{a}) shall apply for ductile reinforced concrete caissons, piles, and drilled shafts:

MCE: $\varepsilon_{cu}^{a} \leq$ lesser of 1/3 ε_{cu} or 1.5 ε_{cc}

where: ε_{cu} = ultimate compressive strain as computed by Mander's model for confined concrete

ε_{cc} = strain at maximum concrete compressive stress as computed by Mander's model for confined concrete.

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11.7.4.7 Strain Limits for Unconfined Concrete

Unconfined compressive strain limits shall be applied to concrete members without sufficient lateral reinforcement to be considered confined. If the lateral reinforcement does not meet the requirements of CBDM for confinement, the section shall be considered unconfined.

For NCL/MCE design, the following allowable concrete unconfined compressive strain limit (ε_{cu}^{a}) applies:

$$\varepsilon_{cu}^{a} = 0.005\text{, for above and below ground concrete}$$

For NCL/MCE design, there are no allowable strain requirements for unconfined cover concrete.

11.7.4.8 Strain Limits for Structural Steel Elements

For NCL/MCE design, the following structural steel allowable tensile strain limits (ε_{su}^{a}) apply:

$$\text{NCL/MCE:} \quad \varepsilon_{su}^{a} \leq 2/3\ \varepsilon_{su}$$

where: ε_{su} = ultimate tensile strain

Structural steel allowable compressive strain limits shall be determined based upon governing local or global buckling in accordance with AASHTO LRFD with Caltrans Amendments, using expected material properties.

11.7.4.9 Foundation Rocking Capacity

For NCL/MCE and OPL/OBE design, where foundation rocking is allowed per Section 11.7.2.1, the foundation rocking capacity shall be determined as per Section 11.7.3.16.

11.7.4.10 Material Properties for Capacities

For NCL/MCE design, expected material properties shall be used in calculating capacities, except shear. For seismic shear capacities, nominal material properties shall be used. Expected material properties shall conform to CSDC for concrete members and AASHTO LRFD with Caltrans Amendments for structural steel members.

For OPL/OBE design, nominal material properties shall be used in calculating capacities.

11.7.4.11 Shear Capacity

For NCL/MCE design, the shear capacity of ductile components shall conform to CSDC for concrete members and AASHTO LRFD with Caltrans Amendments for structural steel members.

11.7.4.12 Joint Internal Forces

Continuous force transfer through the column/superstructure and column/footing joints shall conform to CSDC. These joint forces require that the joint have sufficient over-strength to

ensure essentially elastic behavior in the joint regions based on the capacity of the adjacent members.

11.7.5 Seismic Performance Evaluation

11.7.5.1 Definition of Essentially Elastic

For both NCL/MCE over-strength and OPL/OBE general design, "essentially elastic" is defined as when the LRFD force capacities (ΦF_N) exceed the over-strength or factored demands.

11.7.5.2 Foundation Rocking

For NCL/MCE and OPL/OBE design, where foundation rocking is allowed per Section 11.7.2.1, evaluation shall be per Section 11.7.3.16.

11.7.5.3 Force Based Design for OPL/OBE

For OPL/OBE design, the maximum force based Demand/Capacity (D/C) Ratio shall be:

$$F_U / \Phi F_N \leq 1.0$$

Where:

F_U = the force demand, as defined in Section 11.7.3.1.

ΦF_N = the LRFD force capacity, as defined in Section 11.7.4.1.

in order to satisfy the OPL performance objectives specified in Section 11.5.1.

11.7.5.4 Displacement Based Design for NCL/MCE

For NCL/MCE design, the maximum displacement Demand/Capacity Ratio shall be:

$$\Delta_D / \Delta_C \leq 1.0$$

Where:

Δ_D = the displacement demand, as defined in Section 11.7.3.2.

Δ_C = the displacement capacity, based on strain limits, as defined in Section 11.7.4.2.

in order to satisfy the NCL performance objectives specified in Section 11.5.1.

11.7.5.5 Capacity Protected Element Design

In order to limit the inelastic deformations to the prescribed element of targeted inelastic response, the plastic moments and shears of the element of targeted inelastic response shall be used in the demand/capacity analysis of any adjacent capacity-protected elements of the structure.

Component 120% over-strength factors for the evaluation of capacity-protected elements shall be applied as specified in CSDC for concrete members and AASHTO LRFD with Caltrans Amendments for structural steel members.

11.7.5.6 Soil Improvement

The Geotechnical Reports required by the *Geotechnical* chapter shall provide information and design parameters regarding soil improvement.

11.7.5.7 Design of Shallow Foundations

The Geotechnical Reports required by the *Geotechnical* chapter shall provide information and design parameters regarding the design of shallow foundations.

Shallow foundations shall be designed as capacity protected structural elements under any loading or combination of loadings, including seismic loads. When designing for footing shear, column-to-footing joint shear, and moments in footings, the column plastic moment and shear shall be used with 120% over strength factors applied.

11.7.5.8 Design of Caissons, Pile, and Drilled Shaft Foundations

The Geotechnical Reports required by the *Geotechnical* chapter shall provide information and design parameters regarding the design of caissons, piles, and drilled shaft foundations.

Caissons, piles, and drilled shaft foundations shall be designed as capacity protected structural elements under any loading or combination of loadings, including seismic loads. When designing for pile/drilled shaft cap shear, column-to-pile/drilled shaft cap joint shear, and moments in pile/drilled shaft cap, the column plastic moment and shear shall be used with 120% over-strength factors applied.

For exceptionally soft soil sites, if below ground plastic hinging is unavoidable in caissons, piles or drilled shafts, then a design variance shall be submitted per the *General* chapter. All seismic related design variances shall be identified and justified in the SDAP, as required in Section 11.3.

The design of caissons, piles, and drill shaft foundations shall be in accordance with the CBDM.

11.7.5.9 Expansion Joint and Hinge/Seat Capacity

Structural expansion joint design shall provide free movement for service loads, and OPL/OBE design. However, hinge restrainers may be designed to limit relative longitudinal expansion joint displacements for OPL/OBE design.

Relative expansion joint displacements (longitudinal, transverse, and vertical) for load cases including OBE shall comply with limits contained within the Track-Structure Interaction section of the *Structures* chapter.

Under NCL/MCE design, local damage to structural expansion joints is allowed, but the damage shall not induce changes to important structural behavior.

Adequate seat length shall be provided to prevent unseating of the structure. Seat width requirements for hinges and abutments shall comply with CSDC. Hinge restrainers may be designed as a secondary line of defense against unseating of girders in accordance with CSDC.

Sacrificial components, such as seat type abutment shear keys, are not subject to capacity protection under NCL/MCE design. However, for Primary Type 1 structures, seat type abutment shear keys shall be designed as essentially elastic for OPL/OBE design, and have sufficient stiffness to criteria in the Track-Structure Interaction section of the *Structures* chapter.

For NCL/MCE design, when excessive longitudinal or transverse seismic displacement must be prevented, non-sacrificial shear keys shall be provided and designed as capacity-protected elements.

11.7.5.10 Columns

Columns shall satisfy the detailing requirements for ductile structural elements as specified in CSDC. Ductile detailing requirements apply to all columns, even those designed to be essentially elastic due to foundation rocking or energy dissipation, seismic response modification, or base isolation systems.

The use of lightweight concrete is not allowed in columns.

The column reinforcement ration shall be kept below 4% to reduce congestion due to added joint reinforcement. Column reinforcement shall not be adjusted for drain pipes or other utilities in potential plastic hinge zones. For column flare design and detailing, CSDC shall apply.

11.7.5.11 Superstructures and Bent Caps

Superstructures and bent caps shall be designed as capacity protected elements and shall conform to the requirements of CSDC.

11.7.5.12 Structural Joints

Structural joints (e.g.: column / superstructure, column / bent cap, or column / footing) shall conform to the requirements of CSDC.

11.8 Passenger Stations and Building Structures

All Primary Type 1 passenger stations and building structures shall be subject to the seismic criteria for Bridges, Aerial Structures, and Grade Separations per Section 11.7.

All Primary Type 2 passenger stations and building structures shall be subject to both NCL/MCE and OPL/OBE seismic criteria herein.

All Secondary passenger stations and building structures owned by the Authority shall be subject to the NCL/MCE seismic criteria herein.

All Secondary passenger stations and building structures owned by Third Parties shall be subject to the applicable Third Party seismic criteria.

11.8.1 Design Codes

For NCL/MCE design of Primary Type 2 structures, ASCE 41 shall apply. Although ASCE 41 is a document originally issued for seismic rehabilitation of existing structures, it is applicable in absence of a similar performance based code for the seismic design of new building structures. Certain criteria herein might exceed those of ASCE 41. If items are not specifically addressed in this or other chapters, ASCE 41 shall be used.

For OPL/OBE design of Primary Type 2 structures, current CBC force based design methods shall apply. Note that the OPL/OBE load combination, as given in the *Structures* chapter, is a strength load combination. No seismic response modification factors shall apply to the OBE demands.

For NCL/MCE design of Secondary structures owned by the Authority, current CBC seismic design shall apply, including applicable use of seismic response modification factors.

Table 11-6 summarizes the applicable seismic design code for each General Classification.

Table 11-5: Applicable Passenger Station and Building Structure Design Codes

Performance/ Design Earthquake	General Classification		
	Primary Type 1	**Primary Type 2**	**Secondary**
NCL/MCE	CBDM [1]	ASCE 41	CBC (Seismic Design)
OPL/OBE	AASHTO/Caltrans [1]	CBC (Strength Design)	--
TSI/OBE	*Structures* chapter	--	--

Notes:
[1] as amended by Section 11.7

11.8.2 Seismic Design Approach

The seismic design approach differs depending upon the design earthquake.

11.8.2.1 NCL/MCE Design Approach

For Primary Type 2 structures, for NCL/MCE design the approach shall be:

- A "weak beam - strong column" approach, plastic hinges shall form in the beams and not in the columns. Proper detailing shall be implemented to avoid any kind of nonlinearity or failure in the joints. The formation of a plastic hinge shall take place in the beam element at a distance not less than twice the beam depth away from the face of the joint by adequate detailing.

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- The structure shall have a clearly defined mechanism for response to seismic loads with clearly defined load path and load carrying systems.
- Each component shall be classified as primary or secondary, and each action shall be classified as deformation-controlled (ductile) or force-controlled (non-ductile). The station or building shall be provided with at least 1 continuous load path to transfer seismic forces, induced by ground motion in any direction, from the point of application to the final point of resistance. All primary and secondary components shall be capable of resisting force and deformation actions within the applicable acceptance criteria of the selected performance level.
- Detailing and proportioning requirements for full-ductility structures shall be satisfied. No brittle failure shall be allowed.

If energy dissipation, seismic response modification, or base isolation systems are used, then a design variance shall be submitted per the *General* chapter. In addition, the use of such systems shall be identified in the SDAP, as discussed in Section 11.3.

11.8.2.2 OPL/OBE Design Approach

For Primary Type 2 structures, for OPL/OBE design, the approach shall be:

- The station or building shall respond as essentially elastic.

11.8.3 Seismic Demands on Structural Components

11.8.3.1 Analysis Techniques – General

The station or building shall be modeled, analyzed, and evaluated as a three-dimensional assembly of elements and components. SSI shall be considered in the modeling and analysis.

Structures shall be analyzed using Linear Dynamic Procedure (LDP), Nonlinear Static Procedure (NSP), or Nonlinear Dynamic Procedure (NDP).

Unless it is shown that the conditions and requirements for LDP or NSP can be satisfied, all structures shall be analyzed using NDP.

11.8.3.2 Linear Dynamic Procedure

LDP shall be used in accordance with the requirements of ASCE 41. This can be either a response spectrum method or time-history method as applicable. Buildings shall be modeled with linear elastic stiffness and equivalent viscous damping values consistent with the behavior of the components responding at or near yield level, as defined in ASCE 41.

When response spectrum analysis is used, modal combination shall be performed using the CQC approach, while spatial combination shall be performed using the square root of the sum of the squares (SRSS) technique.

When the time history method is used, input ground motions shall be applied to a three-dimensional model of the structure. Where the relative orientation of the ground motions cannot be determined, the ground motion shall be applied in the direction that results in the maximum structural demands.

When the time history method is used, seven (7) sets of ground motions shall be used, and the average maximum values of each response parameter (e.g., force or strain in a member, displacement or rotation at a particular location) shall be used for design.

The ground motion sets shall meet the requirements of Section 11.5.2.

For buildings that have 1 or more of the following conditions, LDP shall <u>not</u> be used:

- In-Plane Discontinuity Irregularity, unless it is shown that the building remains linear elastic as per requirements of Section 2.4.1.1.1 of ASCE 41
- Out-of-Plane Discontinuity Irregularity, unless it is shown that the building remains linear elastic as per requirements of Section 2.4.1.1.2 of ASCE 41
- Weak Story Irregularity, unless it is shown that the building remains linear elastic as per requirements of Section 2.4.1.1.3 of ASCE 41
- Torsional Strength Irregularity, unless it is shown that the building remains linear elastic as per requirements of Section 2.4.1.1.4 of ASCE 41
- Building structures subject to potential foundation sliding, uplift and/or separation from supporting soil (near field soil nonlinearity)
- Building structures which include components with nonlinear behavior such as, but not limited to, buckling, expansion joint closure
- When energy dissipation, seismic response modification, or base isolation systems are used
- When the building site is in close proximity (within 12.5 miles [20 km]) to hazardous faults, or for ground motions with near-field pulse-type characteristics, a time history analysis shall be used.

11.8.3.3 Nonlinear Static Procedure

For NSP, a mathematical model directly incorporating the nonlinear load-deformation characteristics of individual components and elements of the building shall be developed and subjected to monotonically increasing lateral loads representing inertia forces in an earthquake until a target displacement is exceeded. Mathematical modeling and analysis procedures shall comply with the requirements of ASCE 41. The target displacement shall be calculated by the procedure described in ASCE 41. At least 2 types of lateral load pattern shall be considered as described in ASCE 41. The pushover analysis shall be performed in 2 principal directions independently. Force-controlled actions shall be combined using SRSS, while deformation-controlled action shall be combined arithmetically. Due to soil properties, the embedded and underground building structures may have different behavior when they are pushed in

opposite directions. In these cases the NSP shall include pushover analysis in 2 opposite directions (for a total of 4 analyses for 2 principal directions). When the response of the structure is not primarily in 1 of the principal directions, the pushover analysis shall consider non-orthogonal directions to develop a spatial envelope of capacity.

For buildings that have 1 or more of the following conditions, NSP shall not be used:

- For buildings that the effective modal mass participation factor in any 1 mode for each of its horizontal principal axes is not 70% or more
- If yielding of elements results in loss of regularity of the structure and significantly alters the dynamic response of the structure
- When ignoring the higher mode shapes has an important effect on the seismic response of the structure
- When the mode shapes significantly change as the elements yield
- When 1 of the structure's main response is torsion
- When energy dissipation, seismic response modification, or base isolation systems are used

11.8.3.4 Nonlinear Dynamic Procedure

For NDP, a mathematical model directly incorporating the nonlinear load deformation characteristics of individual components and elements of the building shall be subjected to earthquake shaking represented by ground motion time histories in accordance with these design criteria. Mathematical modeling and analysis procedures shall comply with the requirements of ASCE 41

When NDP is used, input ground motions shall be applied to a three-dimensional model of the structure. Where the relative orientation of the ground motions cannot be determined, the ground motion shall be applied in the direction that results in the maximum structural demands.

When NDP is used, seven (7) sets of ground motions shall be used, and the average maximum values of each response parameter (e.g., force or strain in a member, displacement or rotation at a particular location) shall be used for design.

The ground motion sets shall meet the requirements of Section 11.5.2.

As a minimum, NDP shall comply with the following guidelines:

- Dead and required live loads shall be applied as an initial condition.
- In case of embedded building structures, hydrostatic pressure, hydrodynamic pressure, earth pressure, and buoyancy shall be applied along with dead and required live loads. Where these loads result in reducing other structural demands, such as uplift or

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overturning, the analyses shall consider lower and upper bound values of these loads to compute reasonable bounding demands.

- After completion of each time history analysis, it shall be verified that those structural members, which are assumed to remain elastic, and which were modeled using elastic properties, do in fact remain elastic and satisfy strength requirements.
- For the deformation-controlled action members the deformations shall be compared with the strain limits for each performance level as specified in this document.
- For force-controlled action members the force demand shall be resisted by capacities calculated as per ASCE 41, ACI, and AISC.

11.8.3.5 Local Detailed Finite Element Model

Local detailed finite element models shall be considered as tools to better understand and validate the behavior of the structure when it cannot be obtained from the global model.

11.8.3.6 Floor Diaphragm

Mathematical models of buildings with stiff or flexible diaphragms shall account for the effects of diaphragm flexibility by modeling the diaphragm as an element with in-plane stiffness consistent with the structural characteristics of the diaphragm system.

When there is interest in the response of equipment installed on the floor diaphragm, proper modeling of the floor shall be made to capture vertical vibration modes of the floor.

11.8.3.7 Building Separation

Buildings shall be separated from adjacent structures to prevent pounding as per requirements specified in Section 2.6.10.1 of ASCE 41. Exempt conditions described in Section 2.6.10.2 of ASCE 41 shall not be permitted.

11.8.3.8 Material Properties for Demands

Material properties for demands shall be per Section 11.7.3.6

11.8.3.9 Effective Sectional Properties

Effective sectional properties shall be per Section 11.7.3.4.

11.8.3.10 Foundation Stiffness

Foundation stiffness, including the effects of soil structure interaction, shall be considered for seismic analyses per the *Geotechnical* chapter.

Below grade structures shall be modeled as embedded structures to incorporate and simulate proper soil properties and distribution in the global model. The near field (secondary non-linear) and far field (primary non-linear) effects shall be incorporated in the model. The far field effect shall be modeled with equivalent linear elastic soil properties (stiffness, mass and damping), while the near field soil properties shall represent the yielding behavior of the soil using classic plasticity rules. Input ground motions obtained from a scattering analysis shall be

applied to the ground nodes of the soil elements. The Geotechnical Reports required by the *Geotechnical* chapter shall provide information relative to the scattering analysis.

At-grade and above-grade buildings shall be connected to the near field soil with nonlinear properties when the soil behavior is expected to be subjected to high strains near the structure. The scattered foundation motions shall be applied to the ground nodes of the soil elements.

11.8.3.11 Boundary Conditions

In cases where the building is adjacent to or connected to other structures which are not included in the model, the model shall contain appropriate elements at its boundaries to capture mass and stiffness effects of the adjacent structures.

After completion of static or dynamic analysis, a check shall be performed to verify that the boundary conditions and element properties are consistent with initial modeling assumptions.

11.8.3.12 Multidirectional Seismic Effects

The ground motions shall be applied concurrently in 2 horizontal directions and vertical direction as per ASCE 41. In the demand and capacity assessment of deformation-controlled actions, simultaneous orthogonality effects shall be considered.

11.8.3.13 Load and Load Combinations

Seismic loads and load combinations shall comply with the requirements of the *Structures* chapter. For embedded and underground buildings hydrostatic pressure, hydrodynamic pressure, earth pressure and buoyancy shall be included in addition to dead load and live load. Differential settlement shall be included for buildings.

11.8.3.14 Accidental Horizontal Torsion

In a three-dimensional analysis, the effect of accidental torsion shall be included in the model. Accidental torsion at a story shall be calculated as the seismic story force multiplied by 5% of the horizontal dimension at the given floor level measure perpendicular to the direction of applied load. Torsion needs not be considered in buildings with flexible diaphragms.

11.8.3.15 P-Δ Effects

Geometric nonlinearity or P-Δ effects shall be incorporated in the analysis.

11.8.3.16 Overturning

Structures shall be designed to resist overturning effects caused by seismic forces. Each vertical-force-resisting element receiving earthquake forces due to overturning shall be investigated for the cumulative effects of seismic forces applied at and above the level under consideration. The effects of overturning shall be evaluated at each level of the structure as specified in ASCE 41. The effects of overturning on foundations and geotechnical components shall be considered in the evaluation of foundation strength and stiffness as specified in ASCE 41.

11.8.3.17 Seismic Capacities of Structural Components

The component capacities shall be computed based on methods given in Chapters 5 and 6 of ASCE 41 for steel and concrete structures, respectively. However, strain limits described in Sections 11.7.4.5 and 11.7.4.8 of this document shall be used.

11.8.3.18 Material Properties for Capacities

Material properties for capacities shall be per Section 11.7.4.10.

11.8.3.19 Capacity of Members with Force-Controlled Action

Axial force, bending moment and shear capacities shall be computed in accordance with the requirement of ASCE 41.

11.8.3.20 Capacity Protected Element Design

For NCL/MCE design, pre-determined structural components may undergo flexural plastic hinging, and 120% over strength factors shall be applied to capacity protected members to protect against brittle failure mechanisms. All other structural components not pre-determined for flexural plastic hinging shall be designed to remain elastic under the MCE.

For OPL/OBE design, the structure shall respond as essentially elastic.

Chapter 12

Structures

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Revision	Date	Description
0	13 Mar 12	Initial Release, R0
0.1	07 Dec 2012	Addendum 7- CP01
0.2	Dec 2012	EXECUTION VERSION

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Acronyms

Authority	California High-Speed Rail Authority
CWR	Continuous Welded Rail
HST	High-Speed Train
LRFD	Load and Resistance Factor Design
OCS	Overhead Contact System
RLD	Relative Longitudinal Displacement
RVD	Relative Vertical Displacement
REJ	Rail Expansion Joints
SEJ	Structural Expansion Joints
TCL	Track Centerline
TOR	Top of Rail
VTSI	Vehicle-Track-Structure Interaction

Note: Additional Acronyms are found in Section 12.2 and Table 12-5 of this chapter.

12 Structures

12.1 Scope

This chapter provides design criteria for structures supporting California High-Speed Train (HST) service including but not limited to bridges, aerial structures, grade separations, earth retaining structures, cut-and-cover underground structures, station structures, surface facilities and buildings.

12.2 Regulations, Codes, Standards, and Guidelines

Refer to the *General* chapter for requirements pertaining to regulations, codes, and standards. Design shall meet applicable portions of the general laws and regulations of the State of California and of respective local authorities. Facilities shall be designed in accordance with applicable portions of the following standards and codes:

- American Concrete Institute (ACI)
  - ACI 318: Building Code Requirements for Reinforced Concrete
  - ACI 350: Code Requirements for Environmental Engineering Concrete Structures and Commentary
- American Welding Society (AWS)
  - AWS D1.1/D1.1M Structural Welding Code-Steel
  - AWS D1.8/D1.8M Structural Welding Code-Seismic Supplement
- American Association of State Highway and Transportation Officials (AASHTO)/AWS D1.5M/D1.5 Bridge Welding Code
- California Building Code (CBC)
- American Railway Engineering and Maintenance-of-Way Association (AREMA) Manual for Railway Engineering
- American Institute of Steel Construction (AISC), Steel Construction Manual,
- American Society of Civil Engineers (ASCE) 7-05; Minimum Design Loads for Buildings and Other Structures
- California Occupational Safety and Health Administration (Cal/OSHA) Department of Industrial Relations
- California Department of Transportation (Caltrans) Bridge Design Manuals

  - Bridge Design Specification (CBDS) - AASHTO LRFD Bridge Design Specification with California Amendments
  - Bridge Memo to Designers Manual (CMTD)
  - Bridge Design Practices Manual (CBPD)
  - Bridge Design Aids Manual (CBDA)
  - Bridge Design Details Manual (CBDD)
  - Seismic Design Criteria (CSDC)
  - Office of Special Funded Projects (OSFP) Information and Procedures Guide
- Code of Federal Regulations (CFR)
- United States Department of Transportation Federal Highway Administration; Technical Manual for Design and Construction of Road Tunnels – Civil Elements; Publication No. FHWA-NHI-09-010

Other international standards are used in the development of these criteria, including the following:

- European Standard EN 1991-2:2003 Actions on Structures – Part 2: Traffic Loads on Bridges
- European Standard EN 1990:2002 +A1 Basis of Structural Design annex A2: Application to Bridges
- International Federation for Structural Concrete (FIB) Model Code for Concrete Structures, 1990 (For Time Dependent Behavior of Concrete)

12.3 Types of Structures

Structures supporting high-speed train service are classified as the following:

- Bridges – HST trackway structures crossing rivers, lakes, or other bodies of water
- Aerial Structures – elevated HST trackway structures including bridges, viaducts and HST grade separations
- Grade Separations – structures separating trackways from railroad, highway or pedestrian usage
- Earth Retaining Structures – including U-walls, trenches, and retaining walls
- Cut-and-Cover Underground structures – including cut-and-cover line structures
- Bored Tunnels
- Mined Tunnels

- Surface Facilities and Buildings – including station buildings, station parking structures, secondary and ancillary buildings, sound walls, and miscellaneous structures
- Underground Ventilation Structures
- Underground Passenger Stations
- Equipment and Equipment Supports

12.4 Structural Design Requirements

Structures shall be designed for specified limit states to achieve the objectives of constructability, safety, and serviceability, with the consideration of inspectability, and maintainability, as specified in AASHTO LRFD with California Amendments unless otherwise modified here.

12.4.1 Structural Design Parameters

- Structures shall be designed for the appropriate loadings and shall comply with the HST structure gauge per the *Trackway Clearances* chapter.
- The design life for structures shall be 100 years. Elements such as expansion joints and bearings that need to be replaced in the life of the structures, the Contractor shall evaluate the life of each element and specify the replacement procedures which the element can be replaced within the non-operation hours of the HST service.
- Requirements for noise and vibration are defined in the environmental documents including materials and specific locations and measurements.
- Structural design criteria shall apply to structures adjacent to, above, or below the HST tracks and which performance could directly affect HST operation. This includes aerial structures carrying HSTs and newly constructed highway or ancillary structures which will directly affect the HST operations.
- Structures shall be designed so that the elements normally replaced during maintenance can be readily replaced with minimal impact to HST operations.
- The bridges and aerial superstructures supporting HSTs shall be designed to meet stiffness requirements in order to meet serviceability and comfort requirements for HST operation.
- Permanent and temporary structures including falsework shall be designed in accordance with the clearance requirements. Clearance requirements for falsework are only applicable where the falsework is erected over an operational road or railway.
- Design of structures shall consider loads and effects due to erection equipment, construction methods, and sequence of construction.
- Design and construction of HST facilities shall comply with the approved and permitted environmental documents.

- Only non-flammable materials are allowed in construction. Timber is allowed in construction of falsework.

12.4.2 Seismic Design

For definition of structural classification as Primary or Secondary structures, refer to the *Seismic* chapter. For seismic design criteria for Primary and Secondary structures, as defined in the *Seismic* chapter, refer to the *Seismic* chapter.

12.5 Permanent and Transient Loads and Load Factors for Structures Supporting HST

This section specifies the loads and forces, load factors and load combinations for the application of permanent and transient loads for structures directly supporting HST. This section defines loads specific to bridges, aerial structures, and grade separations. These loads are applicable to earth retaining structures and cut-and-cover structures.

Facility loads, such as those for buildings and stations not supporting high-speed trains, are specified in Section 12.7 - Structural Design of Surface Facilities and Buildings.

For structures carrying highway loads, AASHTO LRFD with Caltrans Amendments shall apply with supplementary provisions herein to account for loads or seismic performance criteria specific to HST operations.

The dynamic analyses to determine dynamic impact factors and ensure the passenger comfort associated with HST rolling stock loadings and the requirements of the track-structure interaction are defined in Section 12.6 - Track-Structure Interaction.

12.5.1 Permanent Loads

12.5.1.1 Dead Load (DC, DW)

The dead load shall include the weight of structure components, appurtenances, utilities attached to the structure, earth cover, finishes, and permanent installations such as tracks, ballast, conduits, piping, safety walkways, walls, sound walls, electrification and utility services.

In the absence of more precise information, the unit weights specified in Table 12-1 shall be used for dead loads.

DC refers to the dead load of structural components and permanent attachments supported by the structure including, tracks, ballast, plinths, cable troughs, parapet walls, sound walls, overhead contact system (OCS), etc.

DW refers to the dead load of non-structural attachments which are permanent or non-permanent attachments including, utilities, cables, finishes, etc.

If applicable, dead load shall be applied in stages to represent the sequence required to construct the structure. Analysis shall consider the effect of the maximum and minimum loading imposed on the structure during construction or resulting from placement or removal of earth cover.

Table 12-1: Unit Weight of Common Materials

Item	Unit Weight	Reference
Electrification (OCS and fastenings)	100 pounds per foot of track	CHSTP (see note 2)
OCS poles and support	See Section 12.5.3.1	CHSTP
Cable trough including walkway surface without OCS pole	1400 plf each	CHSTP
Ballast	140 pcf	AASHTO LRFD with Caltrans Amendments
Ballasted track not including rail and fastener systems	3800 pounds per foot per track, including ties, (add 1000 plf in superelevated zones)	CHSTP
Parapet wall	800 pounds per foot each side	CHSTP
Rails and fasteners (no ties) including special trackwork	200 pounds per foot of track	AREMA
Non-ballasted track & non-ballasted track base not including rail and fastener systems	2500 pounds per foot per track, (add 1000 plf in superelevated zones)	CHSTP
Soils	See Geotechnical reports described in the *Geotechnical* chapter	—
Sound wall material (clear, 1 inch thick)	65 pounds per foot for 14-foot height from TOR placed above concrete parapet	CHSTP
Systems cables in trough	200 pounds per foot of track	CHSTP

Notes:
1. For materials not listed, see AASHTO LRFD with Caltrans Amendments.
2. CHSTP refers to the weights of internal systems requirements necessary for HST operations.

12.5.1.2 Downdrag Force (DD)

Possible development of downdrag on piles or shafts shall be considered. Recommended negative skin friction values shall be as provided for the particular site in the Geotechnical reports described in the *Geotechnical* chapter or as a minimum see AASHTO LRFD with Caltrans Amendments Article 3.11.8.

12.5.1.3 Earth Pressure (EV, EH)

Substructure elements shall be proportioned to withstand earth pressure. Recommended soil parameters, earth pressures and loads due to surcharges shall be as provided for the particular

site in the Geotechnical reports described in the *Geotechnical* chapter. See the *Geotechnical* chapter for determination of pressures acting on earth retaining structures. If site specific design data is not available, use AASHTO LRFD with Caltrans Amendments Article 3.11.

A. Vertical Earth Pressure (EV)

Depth of cover shall be measured from the ground surface or roadway crown, or from the street grade, whichever is higher, to the top of the underground structure. Saturated densities of soils shall be used to determine the vertical earth pressure. Recommended values given in the *Geotechnical* chapter shall be used.

B. Lateral Static Earth Pressure (EH)

For structures retaining draining cohesionless (granular) soil, lateral earth pressure shall be determined in accordance with the *Geotechnical* chapter. For structures retaining other soil types, the lateral soil pressure shall be in accordance with the recommendations specified in the *Geotechnical* chapter.

C. Lateral Seismic Earth Pressure

For increases in earth pressures caused by seismic actions see the *Geotechnical* chapter.

12.5.1.4 Earth Surcharge (ES)

Surcharge loads (ES) are vertical or lateral loads resulting from loads applied at or below the adjacent ground surface. Procedures for determining surcharge load shall be as given in the Geotechnical reports described in the *Geotechnical* chapter.

12.5.1.5 Earth Settlement Effects (SE)

Earth settlement effects (SE) are forces or displacements imposed on a structure due to either uniform or differential settlement under sustained loading. Recommended values of settlement as given in the Geotechnical Reports described in the *Geotechnical* chapter shall be used.

Tolerable settlement on foundations shall be developed by the designer consistent with the function and type of structure, fixity of bearings, anticipated service life, and consequences of unacceptable displacements on structural and operational performance. Operational settlement limits are listed in the *Geotechnical* chapter.

At and near water crossings, scour potential shall also be considered for earth settlement effects.

12.5.1.6 Creep Effects (CR)

For the effects due to creep of concrete (CR), the requirements in AASHTO LRFD with Caltrans Amendments Article 5 shall be used.

12.5.1.7 Shrinkage Effects (SH)

For the effects due to shrinkage of concrete (SH), the requirements in AASHTO LRFD with Caltrans Amendments Article 5 shall be used.

12.5.1.8 Secondary Forces from Prestressing (PS)

Secondary forces from prestressing (PS) shall be accounted for in the design. Such secondary forces arise during prestress of statically indeterminate structures, which produce additional internal forces and support reactions.

12.5.1.9 Locked-in Construction Forces (EL)

Miscellaneous locked-in construction force effects (EL) resulting from the construction process shall be considered. Such effects include jacking apart adjacent cantilevers during segmental construction.

12.5.1.10 Water Loads (WA)

The effects of ground water hydrostatic force, including static pressure of water, buoyancy, stream pressure, and wave loads (WA) shall be considered using the requirements in AASHTO LRFD with Caltrans Amendments Article 3.7. Recommended values given in the Geotechnical Reports described in the *Geotechnical* chapter shall be used. Refer to Section 12.11.2.7 for Hydrostatic pressure for trench and cut-and-cover structures.

Adequate resistance to flotation shall be provided at sections for full uplift pressure on the structure foundation, based upon the maximum of either the maximum probable height of the water table defined in the Geotechnical Reports described in the *Geotechnical* chapter or the maximum flood condition based on the drainage requirements in the *Drainage* chapter. For the completed structure, uplift resistance shall consist of the dead weight of the completed structure and the weight of backfill overlying the structure (within vertical planes drawn through the outer edges of the structure roof and through the joints).

Hydrostatic pressure shall be applied normal to surfaces in contact with groundwater with a magnitude based on the height of water table and the applicable water density.

The change in foundation condition due to scour shall be investigated per AASHTO LRFD with Caltrans Amendments Article 3.7.5.

12.5.2 Transient Loads

12.5.2.1 Live Loads (LLP, LLV, LLRR, LLH, LLS)

Live loads are due to high-speed trains, other trains (not HST), Amtrak, passenger rail, shared-use rail trains, highway loads, construction equipment, and pedestrians.

A. <u>Floor, Roof, and Pedestrian Live Loads (LLP)</u>

For the force effects due to floor and roof live loads (LLP), refer to Section 12.7 - Structural Design of Surface Facilities and Buildings. Section 12.7 includes provisions for aerial trackway supporting service walkways.

B. High-Speed Train Live Loads (LLV)

The project specific rolling stock has not yet been determined. Once the rolling stock is determined, the live load criteria will be included. Trainsets similar to those being considered are presented in Section 12.6.

C. Shared-Use Track Train Live Loads (LLRR)

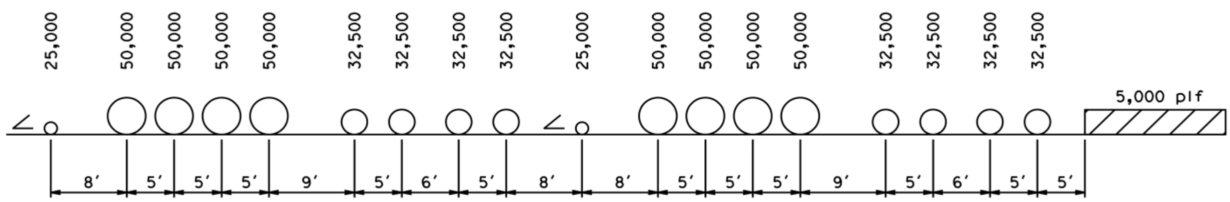
Structures that will support shared service with another railroad system such as AMTRAK, Caltrain, Metrolink, UPRR, BNSF, etc., have specific criteria that must be followed in addition to the requirements provided herein for high-speed trains.

AMTRAK loading is describes in Section 12.5.2.1-E below. Additionally, design shall meet the requirements described in the *Seismic* chapter and Section 12.6 - Track-Structure Interaction.

D. Maintenance and Construction Train Live Loads: Cooper E-50 Loading (LLRR)

Structures shall be designed to support maintenance and construction trains, vertical loads are defined as the Cooper E-50 in the AREMA Specification, see Figure 12-1.

Figure 12-1: Cooper E-50 Loading (LLRR)



For the case of multiple tracks on the bridge, LLRR shall be as follows:

- For two tracks, full live load on two tracks.
- For three tracks, full live load on two tracks and one-half on the other track.
- For four tracks, full live load on two tracks, one-half on one track, and one-quarter on the remaining one.
- For more than four tracks, to be considered on an individual basis.

The tracks selected for full live load shall be those tracks which will produce the most critical design condition on the member under consideration.

E. Amtrak Live Loads

Designated segments of the HST alignment are required to be designed to provide for Amtrak service. These segments shall be designed to support Cooper E-50 loads as described in the AREMA Manual. These structure segments shall also be designed to meet the requirements for structures supporting HSTs, including but not limited to track-structure compatibility and the seismic requirements.

These structures shall be designed to resist two axles weighting 75 kips each with a longitudinal spacing of 9.0 feet. This additional loading is required to account for local effects of Amtrak locomotives.

F. Highway Live Loads (LLH)

Facilities required to support highway loads over HST shall be designed to the requirements of AASHTO LRFD with Caltrans Amendments Article 3.6.1. For facilities intended to support highway permit loads, Caltrans guidelines shall be followed for the routing and sizes of the permit vehicles.

G. Live Load Surcharge (LLS)

An area live load surcharge (LLS) shall be applied at the ground surface both over and adjacent to underground structures, as applicable, to account for presence of live load. Live load surcharge results from presence of LLRR, LLV, LLH, possible future roadways, sidewalk live loads, or construction live loads.

Methods for lateral distribution of live load surcharge due to rail loading shall be in accordance with AREMA. Lateral distribution of highway surcharge shall be in accordance with AASHTO LRFD with Caltrans Amendments Article 3.11.6.4.

No impact factors apply to LLS for walls. A reduction of impact for buried components shall be applicable as specified in AASHTO LRFD with Caltrans Amendments Article 3.6.2, with the 33 percent base impact value modified as applicable to LLRR or LLV, as given herein.

Recommended coefficients for lateral surcharge loading shall be as recommended in the Geotechnical reports described in the *Geotechnical* chapter.

H. Live Loading for Fatigue Assessment

For structures carrying high-speed trains, the project specific rolling stock (LLV) plus impact (I) shall be used for fatigue assessment of structures. Various trainsets LLV, that may be selected are described in Section 12.6.6.1 and dynamic impact shall be determined according to the requirements in Section 12.6.6.3. The methods of AASHTO LRFD with Caltrans Amendments Article 3.6.1.4 shall be used to evaluate fatigue loads.

The fatigue assessment shall be performed for structural elements which are subjected to fluctuations of stress. For structures supporting multiple tracks the loading shall be applied to a minimum of 2 tracks in the most unfavorable positions. The fatigue damage shall be assessed over the required structural life of the structure. During maximum service condition there are 2.8 million axle loads per track per year.

12.5.2.2 Vertical Impact Effect (I)

Moving trains and vehicles impart dynamic loads to bridges, which are considered through a dynamic coefficient or impact factor. The static effects of the design train loads, other than centrifugal, traction, braking, nosing and hunting shall be increased by the percentages specified.

Dynamic analysis is required for structures carrying HSTs (LLV) in order to determine impact effects. This is addressed in detail within Section 12.6 –Track-Structure Interaction.

For determining impact factors (I) associated with maintenance and construction train loading (LLRR) on ballasted track, AREMA Specifications shall be used as follows:

Ballasted track:

- Reinforced or prestressed concrete bridges:

$I = 60\%$ where L $\leq$ 14 feet

$I = \frac{225}{\sqrt{L}}$ where 14 feet < L $\leq$ 127 feet

$I = 20\%$ where L > 127 feet

- Steel bridges:

$I = 40 - \frac{3L^2}{1600}$ where L < 80 feet

$I = 16 + \frac{600}{L - 30}$ where L $\geq$ 80 feet

L = span length

For determining impact factors (I) associated with maintenance and construction train loading (LLRR) for direct fixation on concrete non-ballasted track with spans less than 40 feet, European Standard EN 1991-2 shall be used as modified below. For spans longer than 40 feet, AREMA ballasted track impact factors shall be used.

Direct fixation on concrete non-ballasted track:

$$I = 100\left(\frac{2.16}{\sqrt{0.305L} - 0.2} - 0.27\right) \leq 100\% \text{ where L} \leq 40 \text{ feet}$$

L = Span length for member under consideration (main girder, bridge deck, etc.)

The calculated value shall be applied at top of rail (TOR) as a percentage of live load.

An additional ±20 percent imbalance of live load shall be applied to each rail as a vertical force to model the couple caused by potential rocking of the train. The couple shall be applied on each track in the direction which will produce the most unfavorable effect in the member under consideration.

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For determining impact factors (I) associated with highway loading (LLH), AASHTO LRFD with Caltrans Amendments dynamic load allowance, IM as defined in AASHTO LRFD with Caltrans Amendments shall be used.

Impact effect applies to the following:

- Superstructure, including steel or concrete supporting columns, steel towers, legs of rigid frames, and generally those portions of the structure which extend down to the main foundation.
- The portion above the ground line of concrete or steel piles that support the superstructure directly.

Impact effect does not apply to the following:

- Retaining walls, wall-type piers, and piles except those described above.
- Foundations and footings entirely below ground, and base slabs which are in direct contact with earth.
- Floor, roof, and pedestrian live loads (LLP).

12.5.2.3 Centrifugal Force (CF)

For tracks on a curve, centrifugal force (CF) shall be considered as a horizontal load applied toward the outside of the curve. Multiple presence factors shall apply to centrifugal forces. See the *Track Geometry* chapter for the range of radius values.

For centrifugal forces from carrying vehicular traffic, refer to AASHTO LRFD with Caltrans Amendments.

The centrifugal force (CF) is a function of the train live load (LLRR or LLV), speed, and horizontal radius of curvature:

For LLRR, use AREMA requirements

For LLV, CF acts at 6 feet above TOR

$$CF = (LLRR \text{ or } LLV) \times [0.0668 * V^2 * f / R]$$

Where:

V = train speed (mph)

R = horizontal radius of curvature (feet)

f = reduction factor, not to be taken less than 0.35:

f = 1, for LLRR, for $V \leq 75$ mph

$f = 1 - [(V - 75)/621.4] \times [506/V + 1.75] \times [1 - (9.45/L)^{1/2}] \geq 0.35$, for LLRR, $V > 75$ mph

$f = 1$, for LLV, all speeds

L = length in feet of the loaded portion of curved track on the bridge.

If the maximum line speed at the site is in excess of 75 mph, the centrifugal force shall be investigated at 75 mph with a reduction factor of 1.0, and at the maximum line speed with a reduction factor less than 1.0.

The effect of superelevation shall be considered when present. The superelevation effect shifts the centroid of the train laterally producing an unequal transverse distribution between rails. Consideration shall be given to the cases in which the train is moving and at rest condition.

12.5.2.4 Traction and Braking Forces (LF)

A. LLRR

For traction and braking forces (LF) from passenger trains, freight trains, maintenance and construction trains (LLRR) taken from AREMA Section 2.2.3:

Traction force = $N(25\sqrt{L})$ kips, acting 3 feet above TOR

Braking force = $N(45 + 1.2L)$ kips, acting 8 feet above TOR

Where:

L = length in feet of portion of bridge under consideration

N = ratio of Cooper train load to Cooper E80 loading for the sizes of trains that will use the structure (i.e. for Cooper E50, $N = 0.625$)

The LF loads for LLRR are to be distributed over the length of portion of bridge under consideration up to the maximum length of train. Multiple presence factors shall apply.

B. LLV

For traction and braking forces (LF) from high-speed trains (LLV) taken from European Standard Eurocode EN 1991-2, Article 6.5.3:

Traction force = 2.26 kips per linear foot or 25 percent of train load (if known), with a maximum value of 225 kips, acting at TOR

Braking force = 1.37 kips per linear foot or 25 percent of train load (if known), with a maximum value of 1350 kips, acting at TOR

Traction and braking forces will be reviewed and confirmed when the rolling stock is selected.

C. LLH

For braking forces (LF) from highway loading (LLH), AASHTO LRFD with Caltrans Amendments Article 3.6.4 shall be used.

12.5.2.5 Nosing and Hunting Effects (NE)

For structures with non-ballasted track and direct fixation fasteners, nosing and hunting effects (NE) of the wheels contacting the rails shall be accounted by a 22 kip horizontal force applied to the top of the low rail, perpendicular to the Track Centerline (TCL) at the most unfavorable position.

NE is not applicable for the design of bridge decks with ballasted track. NE is not applicable to LLRR and LLH.

NE shall be applied simultaneously with centrifugal force (CF).

12.5.2.6 Wind Loads (WS, WL)

Wind Load on Structures (WS) and Wind Load on Trains (WL) shall be calculated in accordance with requirements in AASHTO LRFD with Caltrans Amendments Article 3.8 with the following modifications:

- The effective wind area shall include the exposed area of all bridge elements, OCS poles, and catenary. For parapets and barriers, shielding of downwind elements from those upwind shall not be considered (i.e., the exposed area shall include the summation of parapets on the bridge).
- The base lateral load for Wind Load on Vehicles (WL) shall be revised to 0.300 klf perpendicular to the train acting 8 feet above the TOR. AASHTO LRFD with Caltrans Amendments Table 3.8.1.3-1 Wind Components on Live Load for skewed angles of incidence shall be revised proportionally to reflect the modified base lateral load.
- For structures that utilize sound walls or wind walls capable of effectively shielding the train from wind loading, consideration may be given to a reduction of WL. The reduction may be taken as the fractional height of train that is shielded by the wall. This reduction shall not exceed 50 percent of WL.

Local design elements such as parapets or components on structures shall be designed to wind loading and slipstream effects. Wind loading shall be calculated per CBC. The wind importance factor shall equal 1.15.

Wind loading for non-conventional bridge types or long-spans will require special attention (e.g., dynamic effects).

Wind loads (WS) on building and station structures are detailed in Section 12.7 – Structural Design of Surface Facilities and Buildings.

Wind loads (WS, WL) on highway structures shall be per AASHTO LRFD with Caltrans Amendments.

12.5.2.7 Slipstream Effects (SS)

A. Aerodynamic Actions from Passing Trains

The passing of high-speed trains subjects structures situated near the track to transient pressure waves. This action may be approximated by equivalent loads acting at the front and rear of the train.

Aerodynamic actions from passing trains shall be taken into account when designing structures adjacent to railway tracks.

The passing of rail traffic subjects any structure situated near the track to a traveling wave of alternating pressure and suction (see Figures 12-2 to 12-7). The magnitude of the action depends mainly on:

- Square of the speed of the train
- Aerodynamic shape of the train
- Shape of the structure
- Position of the structure, particularly the clearance between the vehicle and the structure

The actions may be approximated by equivalent loads at the ends of a train when checking ultimate and serviceability limit states and fatigue. Equivalent loads are given in Sections 12.5.2.7-B to 12.5.2.7-G.

In Sections 12.5.2.7-B to 12.5.2.7-G, the Maximum Design Speed V [mph] shall be taken as the Maximum Line Speed at the site.

At the start and end of structures adjacent to the tracks, for a length of 16.4 feet from the start and end of the structure measured parallel to the tracks, the equivalent loads in Sections 12.5.2.7-B to 12.5.2.7-G shall be multiplied by a dynamic amplification factor of 2.0.

Simple is defined here as smooth, without projections, ribs, or other obstruction.

For aerodynamic actions inside of tunnels, see the *Tunnels* chapter.

Note: For dynamically sensitive structures, the dynamic amplification factor may be insufficient and may need to be determined by a special study. The study shall take into account dynamic characteristics of the structure including support and end conditions, speed of the adjacent rail traffic and associated aerodynamic actions, and the dynamic response of the structure including the speed of a deflection wave induced in the structure. In addition, for dynamically sensitive structures a dynamic amplification factor may be necessary for parts of the structure between the start and end of the structure.

B. <u>Simple Vertical Surfaces Parallel to the Track</u>

Equivalent loads, ± q_{1k}, are given in Figure 12-2 and Figure 12-3.

Figure 12-2: Equivalent Loads q_{1k} for Simple Vertical Surfaces Parallel to the Track for Speeds Less than 125 mph

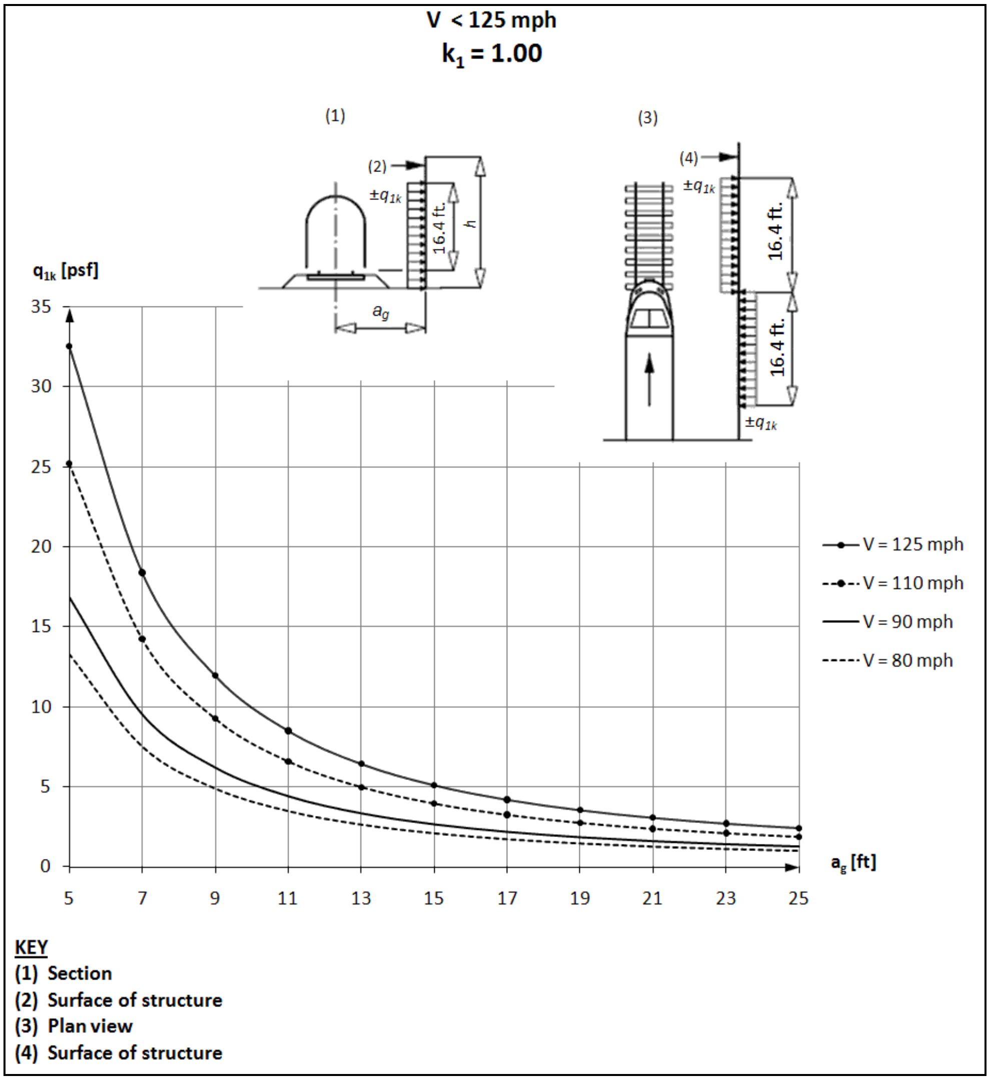
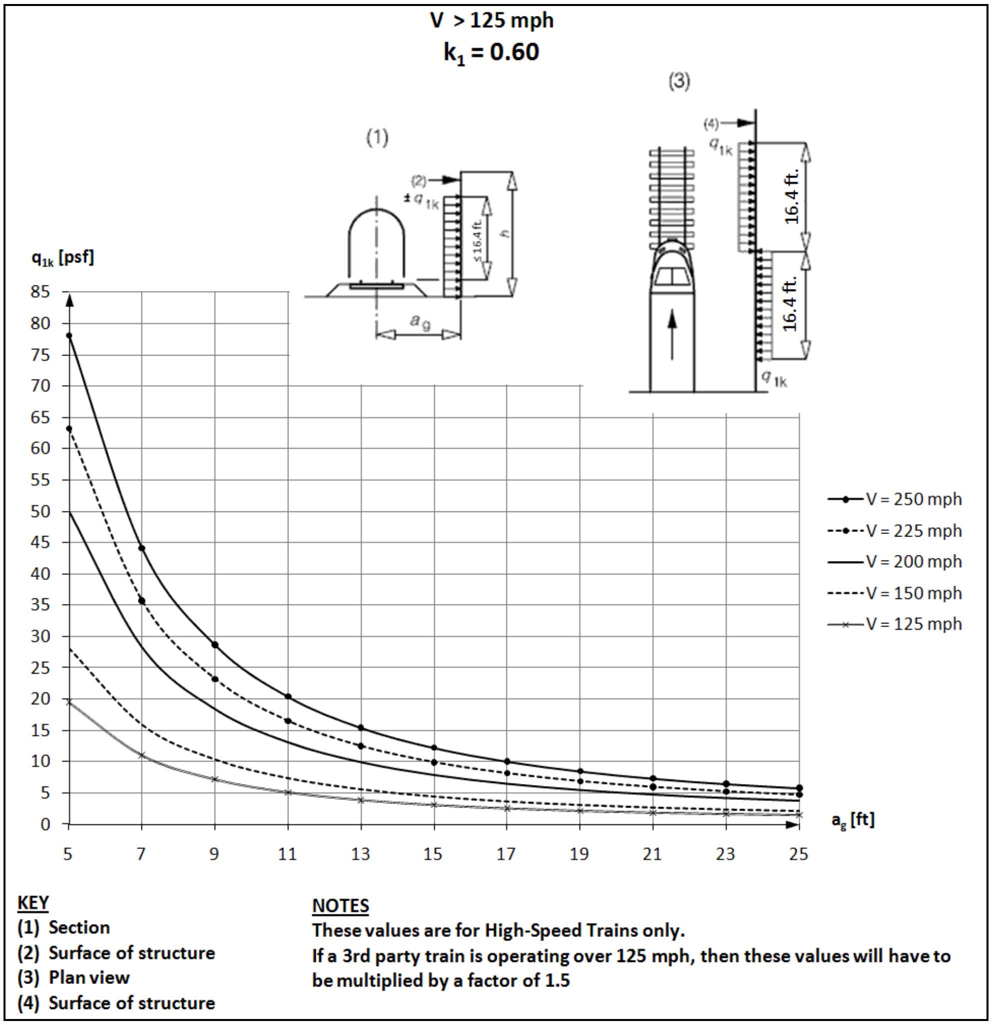


Figure 12-3: Equivalent Loads q_{1k} for Simple Vertical Surfaces Parallel to Track for Speeds Greater than 125 mph



The equivalent loads apply to trains with an unfavorable aerodynamic shape and may be reduced by:

- A factor k_1 = 0.85 for trains with smooth sided rolling stock
- A factor k_1 = 0.6 for streamlined rolling stock (*e.g.* ETR, ICE, TGV, Eurostar or similar)

If a small part of a wall with a height ≤ 3.00 feet and a length ≤ 8 feet is considered (e.g., an element of a wall), the actions q_{1k} shall be increased by a factor k_2 = 1.3.

For surfaces perpendicular to the train, the actions q_{1k} shall be taken from Figure 12-2 and Figure 12-3 for the distance indicated from TCL modified as described in the previous items.

C. <u>Simple Horizontal Surfaces Above the Track (e.g. overhead protective structures)</u>

Equivalent loads, ± q_{2k}, are given in Figure 12-4 and Figure 12-5.

The loaded width for the overhead structural member extends up to 33 feet to either side from the TCL.

Figure 12-4: Equivalent Loads q_{2k} for Simple Horizontal Surfaces Above Track for Speeds Less than 125 mph

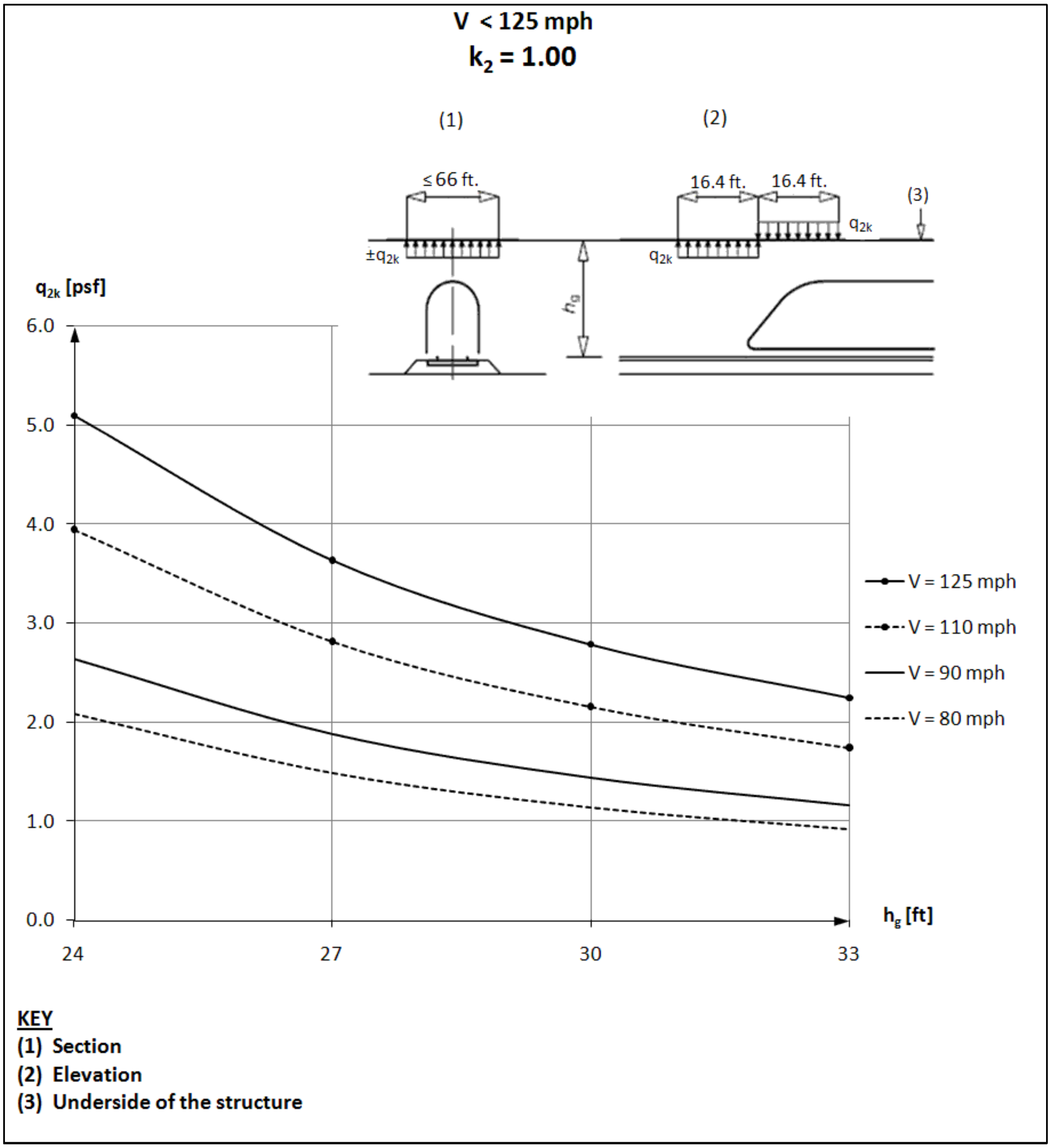
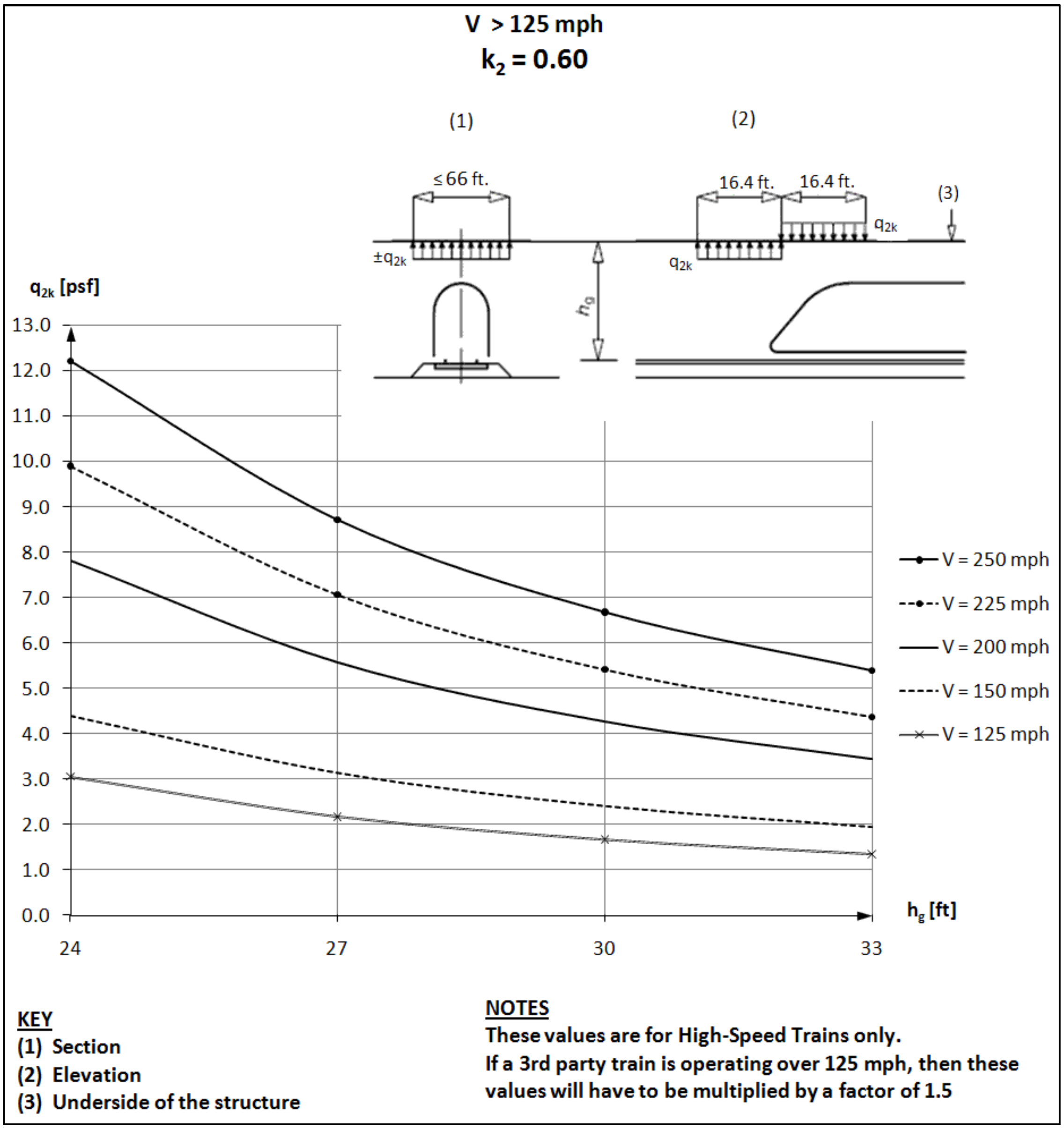


Figure 12-5: Equivalent Loads q_{2k} for Simple Horizontal Surfaces Above Track for Speeds Greater than 125 mph



For trains passing in opposite directions, the actions shall be added. The loading from trains on only two tracks shall be considered.

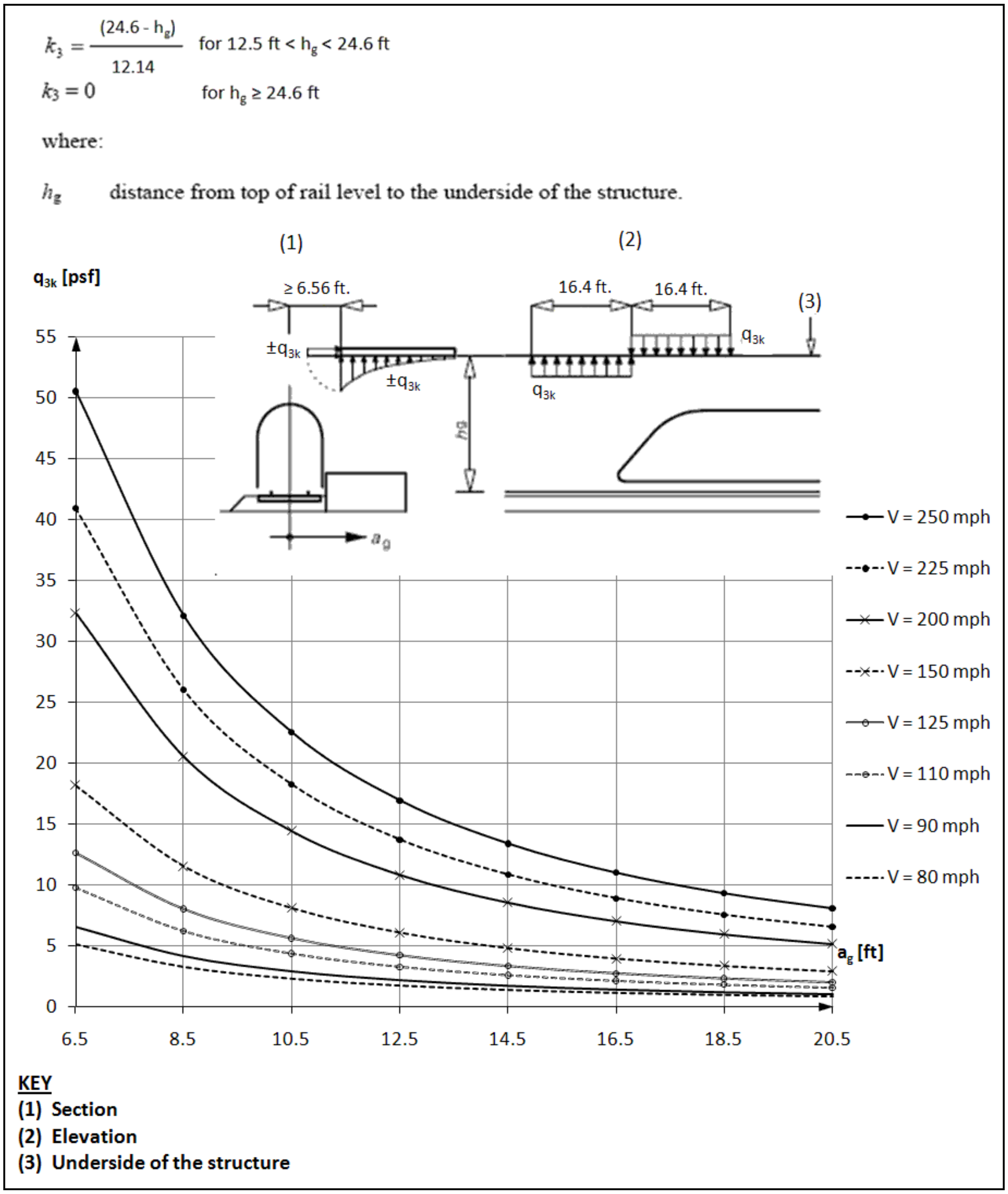
The actions q_{2k} may be reduced by the factor k_1 as defined in Section 12.5.2.7-B.

The actions acting on the edge strips of a wide structure (greater than 33 feet) crossing the track may be multiplied by a factor of 0.75 over a width up to 16.5 feet.

D. <u>Simple Horizontal Surfaces Adjacent to the Track (e.g., platform canopies with no vertical wall)</u>

Equivalent loads, ± q_{3k}, are given in Figure 12-6 and apply irrespective of the aerodynamic shape of the train.

Figure 12-6: Equivalent Loads q_{3k} for Simple Horizontal Surfaces Adjacent to Track



For every position along the structure to be designed, q_{3k} shall be determined as a function of the distance a_g from the nearest track. The actions shall be added if there are tracks on either side of the structural member under consideration.

If the distance h_g exceeds 12.5 feet the action q_{3k} may be reduced by a factor k_3.

E. Multiple-Surface Structures Alongside the Track with Vertical and Horizontal or Inclined Surfaces (e.g., noise barriers, platform canopies with vertical walls, etc.)

Equivalent loads, $\pm q_{4k}$, as given in Figure 12-7 shall be applied normal to the surfaces considered. The actions shall be taken from the graphs in Figure 12-2 and Figure 12-3 adopting a track distance the lesser of:

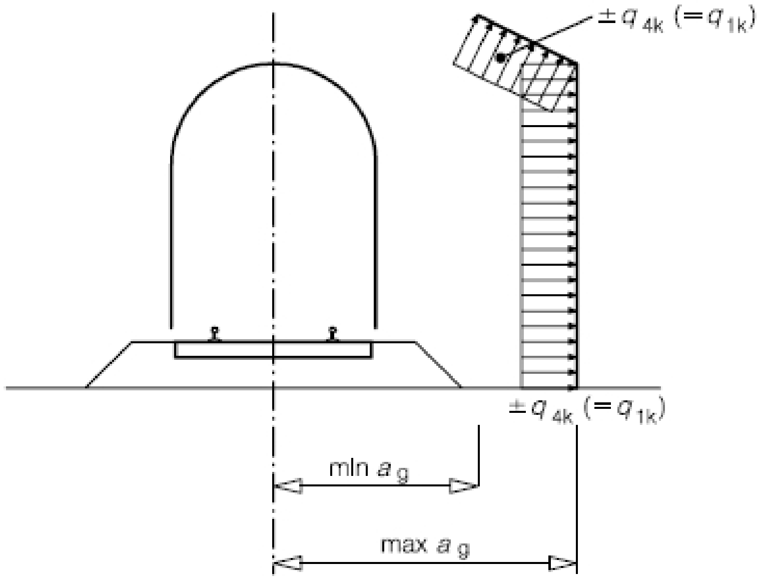
$$a'_g = 2.0 \text{ feet min } a_g + 1.25 \text{ feet max } a_g, \text{ or } 20 \text{ feet}$$

where distances min a_g and max a_g are shown in Figure 12-7

If max $a_g > 20$ feet the value max $a_g = 20$ feet shall be used

The factors k_1 and k_2 defined in Section 12.5.2.7-B shall be used

Figure 12-7: Definition of the Distances min a_g and max a_g from Centerline of Track



F. Surfaces Enclosing the Structure Gauge of the Tracks over a Limited Length (up to 65 feet) (horizontal surface above the tracks and at least one vertical wall, e.g. scaffolding, temporary construction)

Actions shall be applied irrespective of the aerodynamic shape of the train:

- To the full height of the vertical surfaces:

$$\pm k_4 q_{1k}$$

Where:

q_{1k} is determined according to Section 12.5.2.7-B

$k_4 = 2$

- To the horizontal surfaces:

$\pm k_5 q_{2k}$

Where:

q_{2k} is determined according to Section 12.5.2.7-C for only one track,

$k_5 = 2.5$ if one track is enclosed

$k_5 = 3.5$ if two tracks are enclosed

G. Surfaces Perpendicular to or Crossing the Tracks over a Limited Length

Surfaces that are normal to the track such as wayside equipment and signs shall be designed to resist transient air pressure presented in Figure 12-2 and Figure 12-3 on vertical surfaces and Figure 12-4 and Figure 12-5 on horizontal surfaces.

12.5.2.8 Thermal Load (TU, TG)

For uniform (TU) and gradient (TG) temperature effects of the structure, the requirements in AASHTO LRFD with Caltrans Amendments Article 3.12 shall be used. Consideration shall be given to the maximum and minimum ambient temperatures.

12.5.2.9 Frictional Force (FR)

The force due to friction (FR) shall be established on the basis of extreme values of the friction coefficient between sliding surfaces (i.e., at bearing pads). Where appropriate, the effects of moisture, degradation, and contamination of sliding or rotating surfaces upon the friction coefficient shall be considered.

Where applicable, recommended frictional values per AASHTO LRFD with Caltrans Amendments shall be used.

12.5.2.10 Seismic Loads (MCE, OBE)

Detailed, project specific seismic design criteria are presented in the *Seismic* chapter. The *Seismic* chapter defines seismic design philosophies, seismic analysis/demand methodologies, and structural capacity evaluation procedures for the two levels of design earthquakes.

Primary structures shall comply with two performance levels.

12.5.2.11 Hydrodynamic Force (WAD)

Hydrodynamic pressure effects acting on submerged portions of structures due to dynamic motion shall be computed using the method of Goyal and Chopra or by equivalent means.

For possible additional hydrodynamic force effects, see the Geotechnical reports described in the *Geotechnical* chapter.

12.5.2.12 Dynamic Earth Pressures (ED)

Dynamic earth pressure due to seismic motion acting on retaining structures shall be computed using the methods presented in the *Geotechnical* chapter.

12.5.2.13 Derailment Loads (DR)

A. <u>LLRR and LLV</u>

In the event of derailment, the damage to the bridge or aerial structure shall be minimal. Overturning or collapse of the structure shall not be allowed.

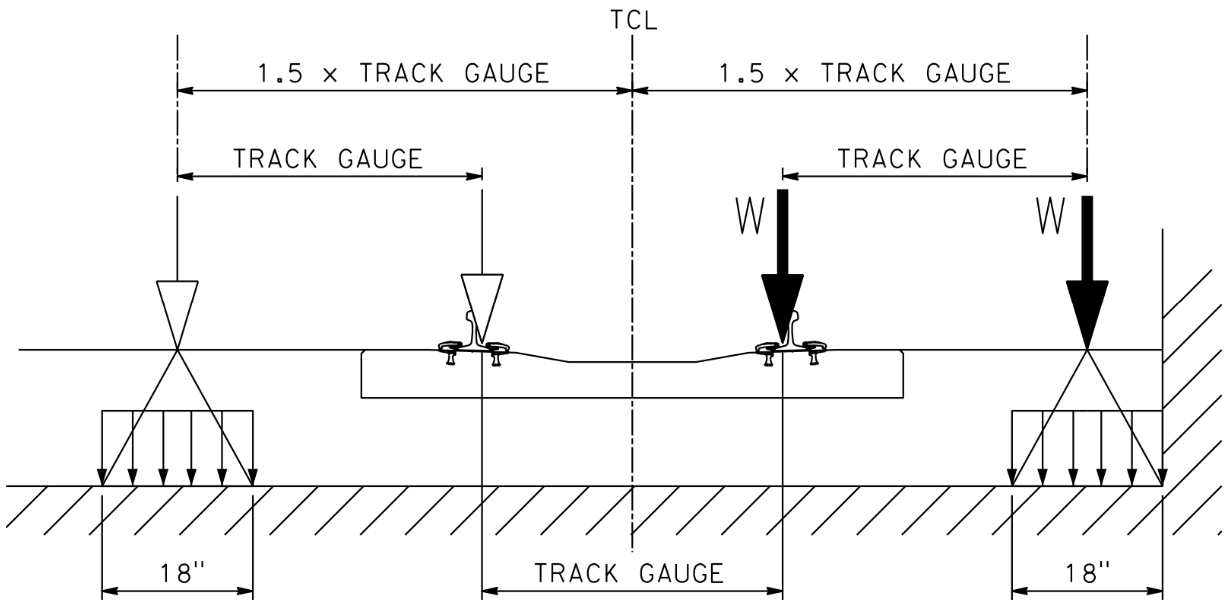
The following design situations shall be considered:

- Case I – Derailment of railway vehicles, with the derailed vehicles remaining in the track area on the bridge deck with vehicles retained by the adjacent rail or a containment wall.
- Case II – Derailment of railway vehicles, with the derailed vehicles balanced on the edge of the bridge and loading the edge of the superstructure (excluding non-structural elements such as walkways).
- Case III – Derailment of a steel wheel impacting the bridge deck between containment barriers shall be evaluated using the heaviest axle loads that potentially use the structure with a minimum of the Cooper E-50. In shared use corridors, larger axle loads shall be considered with the larger axle loads. A 100 percent impact factor shall be applied. This force is used to design the concrete deck slab. See Item B of this section.
- Case IV – Derailment of railway vehicles on a through or semi-through type aerial structure or bridge shall be designed such that the sudden rupture of one vertical or diagonal member of the truss shall not cause collapse of the structure.

For Case I, collapse of any part of the structure is not permitted. Local minor damage, however, is tolerated. The structure shall be designed for the following design loads in the Extreme Loading Combination:

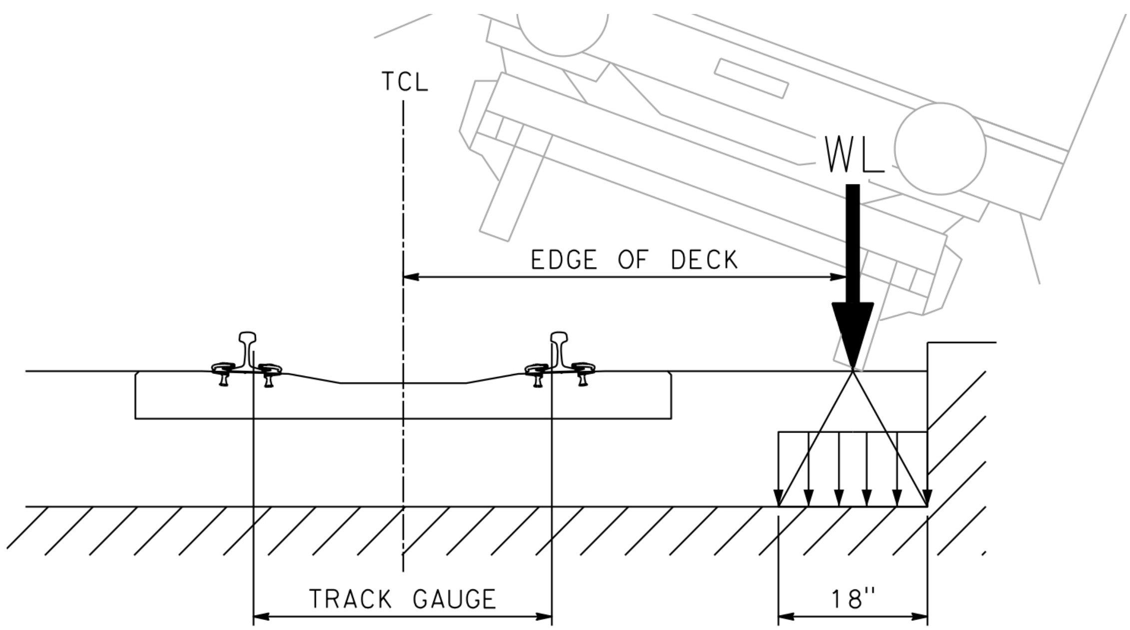
- Cooper E-50 loading, (both point loads W and uniformly distributed loading w) parallel to the track in the most unfavorable position inside an area of width 1.5 times the track gauge on either side of the TCL, or as limited by containment walls. If a short containment wall is used for containment of the train within 1.5 times the track gauge, a coincident horizontal load perpendicular to the track direction shall be used. This horizontal load shall be applied at the top of the containment wall.

Figure 12-8: Derailment Case I



For Case II, the bridge shall not overturn or collapse. For the determination of overall stability a maximum total length of 65 feet of Cooper E-50 uniform load shall be taken as a single uniformly distributed vertical line load, WL, acting on the edge of the structure under consideration. For structures with containment walls, this load shall be applied at the wall face.

Figure 12-9: Derailment Case II



Cases I and II shall be examined separately. A combination of these loads need not be considered.

For ballasted track, lateral distribution of wheel load may be applied, as shown in Figure 12-8 and Figure 12-9.

For Cases I and II, other rail traffic actions shall be neglected for the track subjected to derailment actions. When the structure under consideration carries more than 1 track, only 1 train shall be considered to have derailed, with other tracks containing a vehicle without impact if producing an unfavorable action. Multiple live load presence factors shall apply in this case.

No dynamic factor needs to be applied to the derailment loads for Case 1 and Case II. However, the loads shall be multiplied by the load factor within load combinations. A load factor of 1.0 shall apply to Case III and Case IV.

B. <u>Track Side Containment</u>

Containment walls shall be provided on mainline aerial structures at locations 6 feet minimum to 7 feet maximum from TCL toward the outside edge of deck. The height of the wall shall be minimum 0.67 feet above the level of the adjacent track's lower rail. The containment walls shall terminate at the back of abutment backwalls. A transverse horizontal concentrated load of 35 kips shall be applied at top of the wall at any point of contact. The load shall be distributed over a longitudinal length of 1 foot. A load factor of 1.4 shall be applied to the 35-kip load.

12.5.2.14 Collision Loads (CL)

Collision loads in Sections 12.5.2.14-A, 12.5.2.14-B, and 12.5.2.14-C apply to train impact loads (LLRR, LLV). Section 12.5.2.14-D applies to highway collision loads (LLH). For collision loads on columns or divider walls within the trackway, reference Section 12.7 - Structural Design of Surface Facilities and Buildings.

A. <u>Collision Loads other than at Stations or Platforms</u>

Unprotected structural members within 25 feet of the TCL shall be designed to resist train collision forces of 900 kips parallel and 400 kips perpendicular to the tracks. The loads are applied to a strip 6 feet in length and at a height centered 4 feet above grade. Forces are not applied simultaneously.

B. <u>Collision Loads on Separation Barriers to Deter Intrusion of Derailed Freight/Passenger Trains</u>

The height of barrier wall shall be as shown in the *Rolling Stock and Vehicle Intrusion Protection* chapter. The wall shall be constructed of reinforced concrete. The wall shall extend 15 feet beyond each end of the pier or a wall that is within 25 feet of the TCL, and shall conform to the end conditions presented in the *Rolling Stock and Vehicle Intrusion Protection* chapter.

A moving load of 400 kips transverse to the TCL applied to a strip 6 feet in length at and height centered 4 feet above ground level. A 900 kip longitudinal force shall be applied to the wall at the same elevation. Loads are not applied simultaneously.

C. Structures in Areas beyond Track Ends

Overrunning of rail traffic beyond the end of a track (for example at a terminal station) shall be taken into account as an accidental design situation when the structure or its supports are located in the area immediately beyond the track ends.

The measures to manage the risk shall be based on the utilization of the area immediately beyond the track end and take into account any measures taken to reduce the likelihood of an overrun of rail traffic.

Members supporting structures shall not be located in the area immediately beyond the track ends.

Where structural supporting members are required to be located near to track ends, an end impact wall shall be provided within 20 feet of the track ends in addition to any buffer stop.

The design values for the static equivalent force due to impact on the end impact wall are F_{dx} = 1125 kips for passenger trains and F_{dx} = 2250 kips for freight trains or heavy engines pulling conventional passenger cars. It is recommended that these forces be applied horizontally to a 6-foot wide strip at a level of 4 feet above track level.

D. Highway Vehicle Collision Loads (LLH)

Highway collision load shall be as per AASHTO LRFD with Caltrans Amendments Article 3.6.5.

12.5.3 Miscellaneous Loads

12.5.3.1 Loads and Load Combinations for Design of the Surrounding Area of the Embedded Sleeves of Overhead Contact System Pole Foundation

The embedded sleeves as specified in the Table 12-2 for the OCS pole and down guy anchors in the outside compartment of the cable trough on both sides of structural deck shall be installed at an equal spacing not more than 30 feet in each span along the aerial structure and the offset distance from the centerline of the pier to the centerline of sleeve pattern shall be equal to 1/2 of the equal spacing. If this requirement results in a location within 6 feet of a bridge expansion joint, the location shall be adjusted to provide a spacing of no more than 30 feet to the adjacent OCS foundation anchor point. The loads, load combinations, and limit states specified in Table 12-2 shall be investigated for design of the surrounding area of the embedded sleeves at every OCS foundation to properly transfer the loads to the bridge deck.

Table 12-2: Loads for Design of Overhead Contact System Pole Foundation

Load Combination / Limit State	Location	Load Type	V1 (lbs)	V2 (lbs)	P (lbs)	M1 (lb-ft)	M2 (lb-ft)	Load Factor
Strength I	OCS pole	Dead	1,500	1,500	-22,000	31,500	31,500	1.25
		Wind	See note 4					1.40
Strength II	OCS pole	Dead	1,500	1,500	-22,000	31,500	31,500	1.25
		Slipstream Effects	See note 4					1.75
Strength III	OCS pole	Dead	1,500	1,500	-22,000	31,500	31,500	1.25
		Wind	See note 4					0.65
		Slipstream Effects	See note 4					1.35
Strength IV	Down guy anchor	Dead	14,000	1,000	14,000	1,000	14,000	1.25
Extreme I	OCS pole	Accident	14,000	1,500	-8,000	31,500	294,000	1.0
		Slipstream Effects	See note 4					1.0

Sleeve Pattern and Plate Size			
Anchor Bolt	**Bolt Circle**	**Sleeve Size**	**Plate Size**
4-2.25" Dia.	24"	2.5"	24" x 24"

Notes:

1. V_1 denotes shear force along with axis parallel to track alignment; V_2 denotes shear force along with axis perpendicular to the track alignment.
2. P denotes vertical force, with positive values for tension and negative values for compression.
3. M_1 denotes bending moment about axis parallel to the track alignment; M_2 denotes bending moment about axis perpendicular to the track alignment.
4. Wind load shall be determined according to Section 12.5.2.6; Slipstream effects load shall be determined according to Section 12.5.2.7. Wide flange shape with width of 15 inches, depth of 15 inches, and height of 27 feet shall be used in the calculations of OCS pole foundation loads transferred from OCS pole wind load and slipstream effects load.
5. Loads are assumed at the TOR.

12.5.3.2 Loads for Design of Traction Power Facility Gantry Pole Foundation

The loads specified in Table 12-3 shall be considered for design of each pole foundation of the Traction Power Facility Gantry. On aerial structures, the poles of the gantry are located outside of the cable trough on both sides of structural deck. A total of four gantry pole foundations with spacing of 10 feet, 26 feet, and 10 feet between centerlines of poles shall be assumed on each side of the designated span for the traction power facility gantry. The designer shall design the surrounding areas of the gantry pole foundations to properly transfer the loads to the bridge deck.

Table 12-3: Loads and Load Combinations for Design of Traction Power Facility Gantry Pole Foundation

Load Combination / Limit State	Load Type	V1 (lbs)	V2 (lbs)	P (lbs)	M1 (lb-ft)	M2 (lb-ft)	Load Factor
Strength I	Dead	--	4,500	-11,000	180,000	--	1.25
	Wind	See note 4					1.40
Strength II	Dead	--	4,500	-11,000	180,000	--	1.25
	Slipstream Effects	See note 4					1.75
Strength III	Dead	--	4,500	-11,000	180,000	--	1.25
	Wind	See note 4					0.65
	Slipstream Effects	See note 4					1.35
Strength IV	Dead	--	4,500	-11,000	180,000	--	1.25
	Slipstream Effects	See note 4					0.5
	OBE	See note 5					1.0
Extreme I	Dead	--	4,500	-11,000	180,000	--	1.0
	MCE	See note 5					1.0

Notes:

1. V_1 denotes shear force along with axis parallel to track alignment; V_2 denotes shear force along with axis perpendicular to the track alignment.
2. P denotes vertical force, with positive values for tension and negative values for compression.
3. M_1 denotes bending moment about axis parallel to the track alignment; M_2 denotes bending moment about axis perpendicular to the track alignment.
4. Wind load shall be determined according to Section 12.5.2.6; Slipstream effects load shall be determined according to Section 12.5.2.7. Wide flange shape W24x117 with height of 40 feet, with 100% and 300% wind load area increases in along track and transverse directions respectively to account for the cross beams and attachments, shall be used in the calculations of gantry pole foundation loads transferred from gantry wind load and slipstream effects load.
5. Operating Basis Earthquake (OBE) and Maximum Considered Earthquake (MCE) shall be investigated according to the *Seismic* chapter. The pole shall be considered as cantilever, with weight of 11,000 lbs and the center of mass at 27 feet above the TOR.
6. Loads are assumed at the TOR.

12.5.3.3 Construction Loads and Temporary Structures

A. Temporary Structure Classification

Temporary structures are divided into the following classifications:

- Type A – Temporary structures or structures under temporary conditions which carry or will carry HSTs and/or pass over routes carrying HSTs. Subsequent articles herein apply to Type A structures.
- Type B: – Temporary structures or structures under temporary conditions which do not carry HSTs and do not pass over routes carrying HSTs. These structures shall be designed in accordance with the requirements of the owning/operating agency (e.g., AASHTO LRFD with Caltrans Amendments and CMTD). Structures such as haul bridges used temporarily shall be designed in accordance with CMTD 15-14.

For earth retaining structures and underground structures, see requirements in the *Geotechnical* chapter.

B. Construction Load Combinations

Type A temporary structures or structures under temporary conditions shall be designed to adequately resist conditions at all stages of construction, including applicable construction loads. Construction load combinations, in addition to requirements of Table 12-4, shall include the following:

- Applicable strength load combinations: Dead load factors shall not be taken less than 1.25, with construction dead loads taken as permanent loads. Construction transient live load factors shall not be taken less than 1.5. Wind load factors may be reduced by 20 percent.
- Service 1, as applicable, see AASHTO LRFD Article 3.4.2.
- Seismic requirements for temporary structures are presented in the *Seismic* chapter.

In the absence of specific criteria, a construction live load of 20 psf shall be assumed on the bridge deck.

C. Segmental Construction and Specialized Equipment

Construction load combinations per AASHTO LRFD with Caltrans Amendments Article 5.14.2 "Segmental Construction" shall be considered. The temporary seismic load event as described in the *Seismic* chapter shall be added to the construction load combination at Strength 5 limit state; however a 1.25 load factor shall be used for dead and live loads. The temporary seismic event need not be combined with the dynamic construction load impact due to segment drop or equipment impact. For balanced cantilever construction methods an additional 2 percent of dead load shall be applied to reflect eccentric conditions at the time of a potential seismic event.

12.5.3.4 Track-Structure Interaction Forces

Effects of continuous welded rail (CWR) interaction with the structure through its attachment shall be considered. Design guidance and requirements for this interaction is provided in Section 12.6 - Track-Structure Interaction.

12.5.3.5 Blast Loading

Blast loadings and measures are not specified at this time. See Section 12.13 for general requirements. Refer to AASHTO LRFD with Caltrans Amendments Article 3.15 for aerial structure requirements.

12.5.4 Load Factors and Load Modifiers

Regardless of the type of analysis used, the Eq. 12.5.4-1 shall be satisfied for specified factored force effect and load combinations for each limit state unless otherwise specified in the section:

$$\Sigma\ \eta_i\ \gamma_i\ Q_i \leq \Phi R_n = R_r \quad \text{(Eq. 12.5.4-1)}$$

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Where:

γ_i = load factor applied to force effects (see Tables 12-4, 12-6 and 12-7)

Φ = resistance factor applied to nominal resistance (see AASHTO LRFD with Caltrans Amendments Article 1.3.2.1)

η_i = load modifier relating to ductility, redundancy and importance (see AASHTO LRFD with Caltrans Amendments Article 1.3.2.1)

Q_i = force effect

Rn = nominal resistance

Rr = factored resistance, ΦRn

For loads in which a maximum value of "η_i" produces an unfavorable action, the value of "η_i" shall be equal to 1.05 to account for the design life of the facility. The load modifier is applicable to Strength Limit Load Combinations only.

12.5.4.1 Design Load Combinations

The load combinations to be used for structures carrying HSTs are presented in Table 12-4. The description of the load combinations are as follows:

- "Strength 1" is the basic load combination for normal use.
- "Strength 2" is the load combination for the structure exposed to wind.
- "Strength 3" is the load combination for very high dead load to live load force effect ratios.
- "Strength 4" is the load combination for normal use when exposed to wind.
- "Strength 5" is the load combination for normal use when designing columns for OBE.
- "Extreme 1" is the load combination for derailment.
- "Extreme 2" is the load combination for collision.
- "Extreme 3" is the load combination for extreme seismic events: MCE.
- "Service 1" is the basic service load combination for normal use with wind.
- "Service 2" is the service load combination intended to control yielding of steel structures and slip of slip-critical connections due to train load.
- "Service 3" is the service load combination relating to tension in prestressed concrete superstructures with the objective of crack control and principal tension in the webs of segmental concrete girders.
- "Buoyancy at Dewatering Shutoff" is a service load for evaluation of uplift with a minimum weight structure.

- "Fatigue" is the fatigue and fracture load combination relating to repetitive vertical train loading.

Note that for each load combination, physically achievable subsets (i.e., omitting loads by setting load factor $\gamma_i = 0$) which may govern design shall be considered.

Note that other load cases for train and track structure interaction are contained within Section 12.6 on Track-Structure Interaction.

Table 12-4: Load Combinations for Design of Structures

Load Combinations and Load Factors, γ_i Load Combination/ Limit State	DC DW DD EV EH ES EL PS CR SH	LLP LLV + I LLRR + I LLH + I LLS LF NE CF SS	WA FR	WS	WL	TU	TG	SE	DR	CL	OBE	MCE WAD ED
Strength 1	γ_P	1.75	1.00	--	--	0.50/ 1.20	--	γ_{SE}	--	--	--	--
Strength 2	γ_P	--	1.00	1.40	--	0.50/ 1.20	--	γ_{SE}	--	--	--	--
Strength 3	γ_P	--	1.00	--	--	0.50/ 1.20	--	--	--	--	--	--
Strength 4	γ_P	1.35	1.00	0.65	1.00	0.50/ 1.20	--	γ_{SE}	--	--	--	--
Strength 5	γ_P	γ_{EQ}	1.00	--	--	--	--	--	--	--	1.0	--
Extreme 1	1.00	1.00	1.00	--	--	--	--	--	1.40	--	--	--
Extreme 2	1.00	0.50	1.00	--	--	--	--	--	--	1.00	--	--
Extreme 3	1.00	γ_{EQ}	1.00	--	--	--	--	--	--	--	--	1.00
Service 1	1.00	1.00	1.00	0.45	1.00	1.00/ 1.20	γ_{TG}	γ_{SE}	--	--	--	--
Service 2	1.00	1.30	1.00	--	--	1.00/ 1.20	--	--	--	--	--	--
Service 3	1.00	1.00	1.00	--	--	1.00/ 1.20	γ_{TG}	γ_{SE}	--	--	--	--
Buoyancy @ Dewatering Shutoff	0.80	--	1.10	0.45	--	--	--	--	--	--	--	--
Fatigue	--	1.00	--	--		--	--	--	--	--	--	--

Notes:

1. Additional load combinations are found in Section 12.6 – Track-Structure Interaction
2. Additional loads and load combinations for cut-and-cover construction are found in the Technical Manual for Design and Construction of Road Tunnels – Civil Elements; FHWA-NHI-09-010, March, 2009, Chapter 5
3. γ_{TG} is equal to 1.0 when live load is not considered and 0.50 when live load is considered.

4. γ_{EQ} is equal to 0.0 for MCE. γ_{EQ} is equal to 0.50 for OBE, for a two track system, one train is used. For other track configurations, refer to the *Seismic* chapter.
5. γ_{SE} should equal 1.0, in absence of better criteria. For specific areas where settlement values are uncertain, or if otherwise justified, a larger value should apply.
6. γ_{TU} is equal to the larger value for deformations, and the lesser value for force effects.
7. Derailment load factor taken greater than unity to account for absence of dynamic impact. Refer to Section 12.5.2.13- A.
8. WS load factors for Service I and Strength 4 are larger than the AASHTO LRFD with Caltrans Amendments to account for a higher wind speed under train operations. Operation of trains is assumed to cease at a wind speed of 67 mph.

Table 12-5: Loading Definitions Used in Table 12-4

Permanent Loads	
DC	dead load of structural components and permanent attachments
DW	dead load of non-structural and non-permanent attachment
DD	downdrag force
EV	vertical earth pressure
EH	lateral static earth pressure
ES	surcharge loads
SE	earth settlement effects
EL	locked-in construction forces
PS	secondary forces from prestressing
CR	creep effects
SH	shrinkage effects
WA	water loads & stream pressure
Transient Loads	
LLP	floor, roof, and pedestrian live loads
LLV	high-speed train live loads
LLRR	maintenance and construction train live loads
LLH	highway live loads
LLS	live load surcharge
I	vertical impact effect
LF	traction or braking forces
NE	nosing and hunting effects
CF	centrifugal force
DR	derailment loads
CL	collision loads
WS	wind load on structure
WL	wind load on live load
SS	slipstream effects
TU	uniform temperature effects
TG	gradient temperature effects
FR	frictional force
MCE	Maximum Considered Earthquake

OBE	Operating Basis Earthquake
WAD	hydrodynamic force
ED	dynamic earth pressures

Table 12-6: Load Factors for Permanent Loads, γ_P

Type of Load, Foundation Type, and Method Used to Calculate Downdrag		γ_p Load Factor	
		Maximum	Minimum
DC: Components and Attachments		1.25	0.90
DC: Strength 3 only		1.50	0.90
DD: Downdrag	Piles: α Tomlinson Method	1.40	0.25
	Piles: λ Method	1.05	0.30
	Drilled Shafts: O'Neill and Reese (1999) Method	1.25	0.35
DW: Non-structural dead load and non-permanent attachments		1.50	0.65
EH: Horizontal Earth Pressure			
• Active		1.50	0.90
• At-Rest		1.35	0.90
• AEP for Anchored Walls		1.35	N/A
EL: locked-in construction forces		1.00	1.00
EV: Vertical Earth Pressure			
• Overall Stability		1.00	N/A
• Retaining Walls and Abutments		1.35	1.00
• Rigid Buried Structures		1.30	0.90
• Rigid Frames		1.35	0.90
• Flexible Buried Structures other than Metal Box Culverts		1.95	0.90
• Flexible Metal Box Culverts		1.50	0.90
ES: Surcharge Loads		1.50	0.75

Table 12-7: Load Factors for Permanent Loads due to Superimposed Deformations, γ_P

Bridge Component	PS	CR, SH
Superstructures - Segmental Concrete Substructures supporting Segmental Superstructures (See AASHTO LRFD with Caltrans Amendments Articles 3.12.4 and 3.12.5)	1.00	see γ_p for DC, Table 12-4
Concrete Superstructures – non-segmental	1.00	1.00
Substructures supporting non-segmental superstructures		
• Using I_{gross}	0.50	0.50
• Using $I_{effective}$	1.00	1.00
Steel Substructures	1.00	1.00

12.5.4.2 Resistance Factors

For resistance factors Φ, refer to AASHTO LRFD with California Amendments.

12.6 Track-Structure Interaction

Bridges and aerial structures that support high-speed trains are subject to structural frequency limits, track serviceability limits, rail-structure interaction limits, dynamic structural analysis limits, and dynamic vehicle track-structure interaction analysis limits.

These requirements are concerned with limiting bridge and aerial structure deformations and accelerations, since the structure response can be dynamically magnified under high-speed moving trains. Excessive deformations and accelerations can lead to unacceptable changes in vertical and horizontal track geometry, excessive rail stress, reduction in wheel contact, dynamic amplification of loads, and passenger discomfort.

Track-structure interaction criteria shall apply to any aerial structure whose primary function is to support high-speed train (HST) tracks and therefore critical to track performance. These aerial structures include, but are not limited to: bridges, grade separations, stream crossings, canal crossings, culverts with less than 6 feet of cover, viaducts, and aerial stations supporting HST tracks. For a given aerial structure, all structural discontinuities capable of relative movement shall be considered a structural expansion joint and subject to the applicable criteria.

For criteria related to embankments, abutments, retaining walls, and soil subgrades critical for ensuring track performance, see the *Geotechnical* chapter. For criteria related to track performance in tunnels, see *Tunnels* chapter. Track support discontinuities at transitions between aerial structures and geotechnical elements (including tunnels) shall be considered structural expansion joints and subject to the following applicable criteria.

The following criteria is developed assuming uniform longitudinal rail restraint for structures with maximum structural thermal units (i.e., the maximum distance from a fixed point of thermal expansion to an adjacent fixed point of thermal expansion on a structure) limited to 330 feet. Rail expansion joints are not permitted without an approved design variance.

Table 12-8 summarizes the analysis requirements, including model type, train model/speed, result, and relevant section.

Table 12-8: Analysis Goals

Analysis Goal	Model Type	Train model	Train speed	Result	Section(s)
Frequency Analysis	Dynamic	--	--	Frequency Evaluation	12.6.3.1 to 12.6.3.3
Track Serviceability Analysis	Static, For OBE: Static or Dynamic	Single or Multiple Tracks of Modified Cooper E50	--	Deformation Limits	12.6.4.1 to 12.6.4.10
Rail-Structure Interaction Analysis	Static (linear or non-linear), For OBE: Static or Dynamic	Single or Multiple Tracks of Modified Cooper E50	--	Deformation And Rail Stress Limits	12.6.5.1 to 12.6.5.6
Dynamic Structural Analysis	Dynamic	Single Tracks of High-Speed Passage	90 mph to 1.2 Line Speed (or 250 mph whichever is less)	Dynamic Impact Factor, Vertical Deck Acceleration	12.6.6.1 to 12.6.6.4
Dynamic Vehicle-Structure Interaction Analysis	Dynamic (Structure & Trainset)	Single Track of High-Speed Passage (with Vehicle Suspension)	90 mph to 1.2 Line Speed (or 250 mph whichever is less)	Dynamic Track Safety and Passenger Comfort Limits	12.6.7.1 to 12.6.7.3

12.6.1 Design Requirements

Frequency analysis, track serviceability analysis, rail-structure interaction analysis, and dynamic structural analysis, shall apply for all structures (Standard, Non-Standard, and Complex structures per *Seismic* chapter).

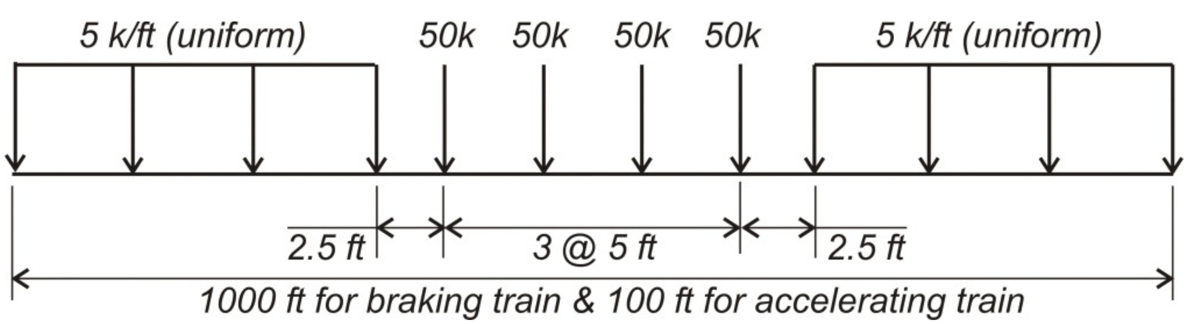
12.6.2 Design Parameters

The following defines loading to be used for track serviceability and rail-structure interaction analysis.

12.6.2.1 Modified Cooper E-50 Loading (LLRM)

Modified Cooper E-50 loading (LLRM) in Figure 12-10 shall be used for track serviceability analysis, and rail-structure interaction analysis. LLRM loading is on a per track basis.

Figure 12-10: LLRM Loading



Nosing effects do not apply to LLRM loading.

12.6.2.2 Vertical Impact Effect (I)

The vertical impact effect (I) used with Modified Cooper E-50 loading (LLRM) shall be per Section 12.5.

Dynamic vertical impact effects (I_{LLV}) caused by high-speed trainsets (LLV) shall be per Section 12.6.6.3.

12.6.3 Frequency Analysis

Frequency limits are placed on the fundamental mode shapes of bridges and aerial structures, in order to ensure well-proportioned structures and minimize resonancy effects.

Modeling requirements are given in Section 12.6.8.

12.6.3.1 Recommended Range of Vertical Frequency of Span

The recommended vertical frequency range is known to favorably resist high-speed train resonance actions. It is recommended that structures be proportioned to fall within this range. Where a structure falls outside the recommended vertical frequency range, additional analysis shall be required per Section 12.6.1.

Vertical frequency analysis shall consider the flexibility of superstructure, bearings, shear keys, columns, and foundations.

For vertical frequency analysis, two conditions shall be investigated:

- Condition #1 – a lower bound estimate of stiffness and upper bound estimate of mass.
- Condition #2 – an upper bound estimate of stiffness and lower bound estimate of mass.

Modeling requirements for lower and upper bound estimates of stiffness and mass are given in Section 12.6.8.

The recommended range for the first natural frequency of vertical deflection, η_{vert} [Hz], primarily due to bending of the span is the following:

$$\eta_{lower} \le \eta_{vert} \le \eta_{upper}$$

Where:

$\eta_{lower} = 262.5/L$ for 13 ft $\le L \le$ 66 ft, or

$\eta_{lower} = 47.645L^{-0.592}$ for 66 ft $\le L \le$ 330 ft, and

$\eta_{upper} = 230.46L^{-0.748}$, for 13 ft $\le L \le$ 330 ft, and

L = effective length of span (feet)

For simple spans, L shall be the span length.

For continuous spans, L shall be the following:

$$L = k\left(L_{\text{average}}\right)$$

Where:

$$L_{\text{average}} = \frac{(L_1 + L_2 + ... + L_n)}{n}$$ = the average span length,

$n =$ the number of spans

$$k = \left(1 + \frac{n}{10}\right) \le 1.5$$

For portal frames and closed frame bridges, L shall be the following:

- Single span: consider as three continuous spans, with the first and third span being the vertical length of the columns, and the second span the girder length.
- Multiple spans: consider as multiple spans, with the first and last span as the vertical length of the end columns, and the interior spans the girder lengths.

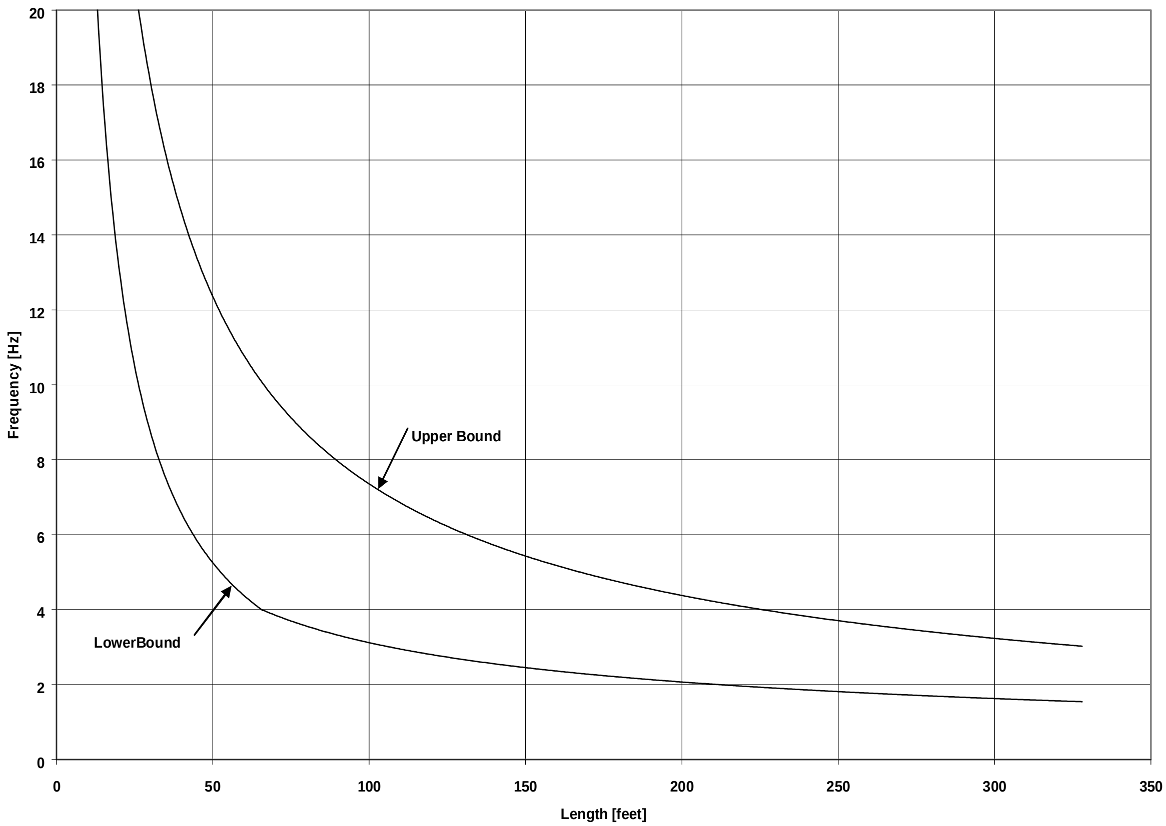
For spans with end diaphragms at abutments (fixed supports at abutments):

- Single span, fixed at one abutment: consider as two continuous spans, with the first span equal to 0.05 times the girder length, and the second span the girder length.
- Single span, fixed at both abutments: consider as three continuous spans, with the first and the third span equal to 0.05 times the girder length, and the second span the girder length.
- Multiple spans, fixed at one abutment: consider as multiple spans, with the first span equal to 0.05 times the adjacent girder length, and the interior spans the girder lengths.
- Multiple spans, fixed at both abutments: consider as multiple spans, with the first and last span equal to 0.05 times the adjacent girder length, and the interior spans the girder lengths.

For single arch, archrib, or stiffened girders of bowstrings, L shall be the half span.

See Figure 12-11 for the recommended range of vertical frequency.

Figure 12-11: Recommended Range of Vertical Frequency



12.6.3.2 Allowable Torsional Frequency of Span

Limiting the allowable torsional frequency favorably resists high-speed train actions.

Torsional frequency analysis shall consider the flexibility of superstructure, bearings, shear keys, columns, and foundations.

For torsional frequency analysis, two conditions shall be investigated, consistent with vertical frequency analysis:

- Condition #1 – a lower bound estimate of stiffness and upper bound estimate of mass
- Condition #2 – an upper bound estimate of stiffness and lower bound estimate of mass

Modeling requirements for lower and upper bound estimates of stiffness and mass are given in Section 12.6.8.

The first torsional frequency, $\eta_{torsion}$, of the span shall be greater than 1.2 times the first natural frequency of vertical deflection, η_{vert}.

12.6.3.3 Allowable Transverse Frequency of Span

Limiting the allowable transverse frequency favorably resists high-speed train actions.

Transverse frequency analysis shall consider the flexibility of superstructure only, excluding the flexibility of bearings, columns, and foundations, assuming the supports at the ends of the span are rigid.

For transverse frequency analysis, a lower bound estimate of stiffness and upper bound estimate of mass shall be used, see Section 12.6.8.

The first natural frequency of transverse deflection, η_{trans}, of the span shall not be less than 1.2 Hz.

12.6.4 Track Serviceability Analysis

Track serviceability analysis, using modified Cooper E-50 loading, provides limits to allowable structural deformations. These track serviceability limits are developed for structures supporting continuous welded rail without rail expansion joints.

Deformation limits are developed for limit states based on maintenance, passenger comfort, and track safety requirements.

For track serviceability analysis, the flexibility of superstructure and substructure (i.e: bearings, shear keys, columns, and foundations) shall be considered.

To avoid underestimating deformations, a lower bound estimate of stiffness and an upper bound estimate of mass shall be used.

Modeling requirements are given in Section 12.6.8.

12.6.4.1 Track Serviceability Load Cases

Track serviceability loads cases shall include the following:

- Group 1a: $(LLRM + I)_1$
- Group 1b: $(LLRM + I)_2 + CF_2 + WA$
- Group 1c: $(LLRM + I)_m + CF_m + WA$
- Group 2: $(LLRM + I)_1 + CF_1 + WA + WS + WL_1$
- Group 3: $(LLRM + I)_1 + CF_1 + OBE$

Where:

$(LLRM + I)_1$ = one track of Modified Cooper E-50 (LLRM) plus impact

$(LLRM + I)_2$ = two tracks of Modified Cooper E-50 (LLRM) plus impact (Section 12.5.2.1-D)

$(LLRM + I)_m$ = multiple tracks of Modified Cooper E-50 (LLRM) plus impact

I = vertical impact factor from LLRR (Section 12.5.2.2)

CF_1 = centrifugal force (one track) (Section 12.5.2.3)

CF_2 = centrifugal force (two tracks) (Section 12.5.2.3)

CF_m = centrifugal force (multiple tracks)

WA = water loads (stream flow) (Section 12.5.2.10)

WS & WL_1 = wind on structure and wind on one 1000' LLRM train (Section 12.5.2.6)

OBE = Operability Basis Earthquake per *Seismic* chapter

Note that Group 1c is used for Section 12.6.4.4 only.

Static analysis and linear superposition of results is allowed for Groups 1b, 1c, and 2.

For determining OBE demands in Group 3, equivalent static analysis, dynamic response spectum, or time history (linear or non-linear) analysis shall be used, as per the *Seismic* chapter and the approved Seismic Design and Analysis Plan. See the *Seismic* chapter for additional OBE modeling requirements.

For track serviceability analysis, non-linear track-structure interaction modeling (see Section 12.6.8.5) is not required, but may be used. For Group 3, superposition of static (i.e., $(LLRM + I)_1 + CF_1$) and either static or dynamic OBE shall be allowed.

12.6.4.2 Vertical Deflection Limits: Group 1a

Vertical deflection limits for Group 1a are to address maintenance, passenger comfort, and track safety issues.

For Group 1a, the maximum static vertical deck deflection (max Δ_{1a}), in the most unfavorable position, shall not exceed the limits given in Table 12-9.

Table 12-9: Vertical Deflection Limits: Group 1a

Limit	Span Length (feet)				
	L ≤ 125	L=175	L=225	L=275	L≥330
max Δ_{1a}	L/3500	L/3180	L/2870	L/2550	L/2200

For span lengths not explicitly referenced in Table 12-9, linear interpolation shall be used.

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12.6.4.3 Vertical Deflection Limits: Group 1b

Vertical deflection limits for Group 1b are to address maintenance, passenger comfort, and track safety issues.

For Group 1b, the maximum static vertical deck deflection (max Δ_{1b}), in the most unfavorable position, shall not exceed the limits given in Table 12-10.

Table 12-10: Vertical Deflection Limits: Group 1b

Limit	Span Length (feet)				
	L ≤ 125	**L=175**	**L=225**	**L=275**	**L≥330**
max Δ_{1b}	L/2400	L/2090	L/1770	L/1450	L/1100

For span lengths not explicitly referenced in Table 12-10, linear interpolation shall be used.

12.6.4.4 Vertical Deflection Limits: Group 1c

Vertical deflection limits for Group 1c are to provide practical guidance for structures containing three or more tracks operating at speeds less than 90 mph. This guidance is consistent with established European codes.

For Group 1c, where the structures support three or more tracks, the loading shall be applied per Section 12.5.2.1-D.

The tracks selected for loading shall be those tracks which will produce the most critical design condition on the member under consideration.

For Group 1c, where structures support three or more tracks, the maximum static vertical deck deflection (max Δ_{1c}), in the most unfavorable position, shall not exceed L/600 for all span lengths.

In the event that structures support 3 or more tracks, and 3 or more trains can be anticipated to be on the same structure at speeds greater than 90 mph, limits defined for Group 1b shall apply. For these structures, loadings representative of service conditions must be developed on a case-by-case basis.

12.6.4.5 Transverse Deflection Limits

Transverse deflection limits are to address maintenance, passenger comfort, and track safety issues.

The transverse deflection within the span (Δ_{trans}), shown in Figure 12-12, shall not exceed the limits given in Table 12-10.

Figure 12-12: Transverse Span Deformation Limits

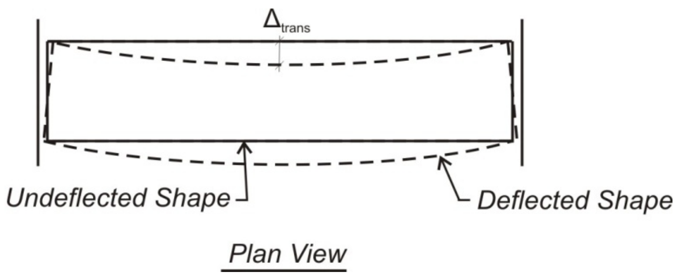


Table 12-11: Transverse Deflection Limits

Group	Δ_{trans} (feet)
1a	$L^2/(864{,}800)$
1b	$L^2/(447{,}200)$
2	$L^2/(276{,}800)$
3	$L^2/(276{,}800)$

12.6.4.6 Rotation about Transverse Axis Limits

Rotation about transverse axis limits are to control excessive rail axial and bending stress, provide traffic safety (i.e., guard against wheel unloading due to abrupt angular changes in track geometry), and provide passenger comfort.

Due to rotation about the transverse axis, imposed axial rail displacement is a linear function of the distance between the rail centroid and top of the bridge bearings. This imposed axial displacement causes rail stress. Rail stress limits may control over passenger comfort and track safety limits.

The maximum total rotation about transverse axis at deck ends (θ_t), shown in Figure 12-13, shall be defined by the following equations:

$\theta_t = \theta$, for abutment condition

$\theta_t = \theta_1 + \theta_2$, between consecutive decks

The maximum relative axial displacement at the level of the rail (δ_t) due to rotation about transverse axis, shown in Figure 12-13, shall also be defined by the following equations:

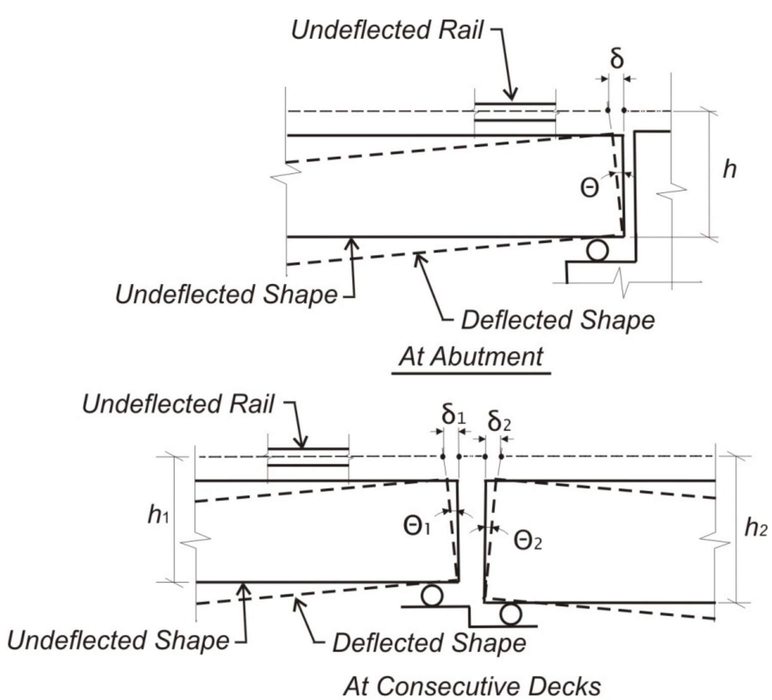
$\delta_t = \theta h$, for abutment condition

$\delta_t = \delta_1 + \delta_2 = \theta_1 h_1 + \theta_2 h_2$, between consecutive decks.

Where:

- θ_t (radians) = total rotation about transverse axis, see Table 12-12
- δ_t (inches) = total relative displacement at the level of the rail, see Table 12-12
- θ (radians) = rotation of the bridge bearing at abutment
- θ_1 (radians) = rotation of the first bridge bearing
- θ_2 (radians) = rotation of the second bridge bearing
- h (inches) = the distance between the rail centroid and the bridge bearing at abutment
- h_1 (inches) = the distance between the rail centroid and the top of the first bridge bearing
- h_2 (inches) = the distance between the rail centroid and the top of the second bridge bearing

Figure 12-13: Rotation about Transverse Axis at Deck Ends



The total rotation about transverse axis (θ_t) and the total relative displacement at the level of the rail (δ_t) shall not exceed the limits given in Table 12-12.

Table 12-12: Rotation about Transverse Axis and Relative Displacement at the Level of the Rail Limits

Group	θ_t (radians)	δ_t (inches)
1a	0.0012	0.33
1b	0.0017	0.33
2	0.0026	0.67
3	0.0026	0.67

12.6.4.7 Rotation about Vertical Axis Limits

Rotation about vertical axis limits are to control excessive rail axial and bending stress, provide track safety, and provide passenger comfort by limiting changes in horizontal track geometry at bridge deck ends.

Due to rotation about the vertical axis, imposed axial rail displacement is a linear function of the distance between the centerline of span and the outermost rail. This imposed axial displacement causes rail stress. Rail stress limits may control over passenger comfort and track safety limits.

The maximum total rotation about vertical axis at deck ends (θ_v), shown in Figure 12-14 shall be defined by the following equations:

$\theta_v = \theta$, for abutment condition

$\theta_v = \theta_A + \theta_B$, between consecutive decks

The maximum axial displacement at the outermost rail (δ_v) due to rotation about vertical axis, shown in Figure 12-15, shall be defined by the following equations:

$\delta_v = \theta w$, for abutment condition

$\delta_v = \delta_A + \delta_B = \theta_A w_A + \theta_B w_B$, between consecutive decks.

Where:

θ_v (radians): total rotation about vertical axis, see Table 12-13

δ_v (inches): total relative displacement at the outermost rail, see Table 12-13

θ (radians): rotation of the bridge at abutment

θ_A (radians): rotation of the first span

θ_B (radians): rotation of the second span

w (inches): the distance between the centerline span and outermost rail centroid at abutment

w_A (inches): the distance between the centerline span and outermost rail centroid of first span

w_B (inches): the distance between the centerline span and outermost rail centroid of second span

Figure 12-14: Rotation about Vertical Axis at Deck Ends – Global View

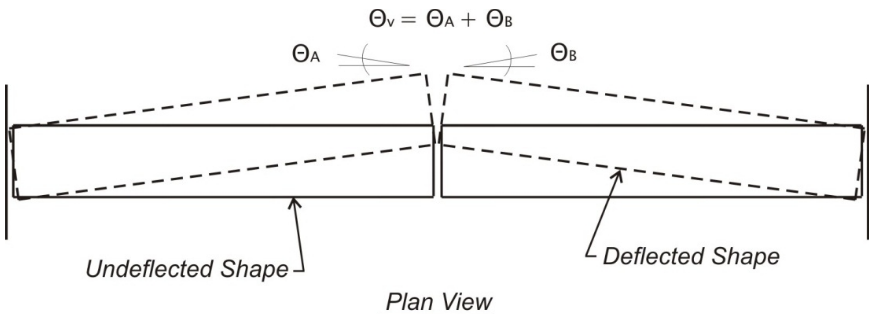
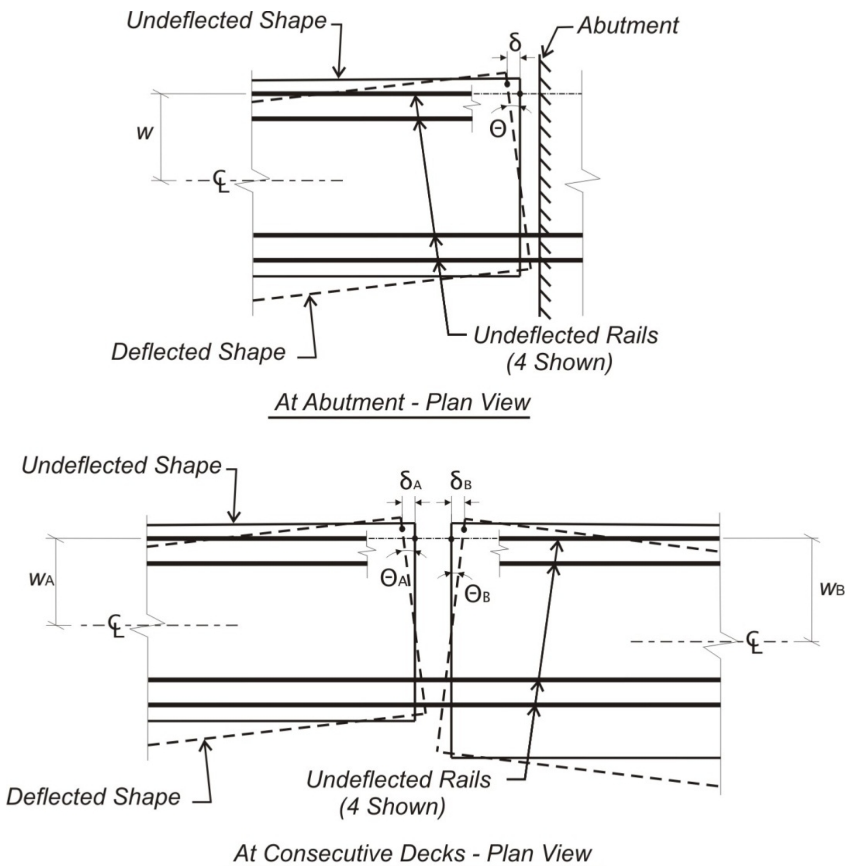


Figure 12-15: Rotation about Vertical Axis at Deck Ends – Local View



The total rotation about vertical axis (θ_v) and the total relative displacement at the outermost rail (δ_v) shall not exceed the limits given in Table 12-13.

Table 12-13: Rotation about Vertical Axis and Relative Displacement at Outermost Rail Limits

Group	θ_v (radians)	δ_v (inches)
1a	0.0007	0.33
1b	0.0010	0.33
2	0.0021	0.67
3	0.0021	0.67

12.6.4.8 Relative Vertical Displacement at Expansion Joints – Track Serviceability

Relative vertical displacements (RVD) at structural expansion joints, δ_v^{EXP}, are limited in order to ensure track safety subject to deck end rotation and vertical bearing deformation. Structural

expansion joints between adjacent deck ends, and between deck ends and abutments shall be considered.

The flexibility of the superstructure and substructure (i.e.: bearings, shear keys, columns, and foundations) shall be considered when calculating RVD.

The relative vertical displacement at expansion joints (δ_V^{EXP}), shown in Figure 12-16, shall not exceed the limits given Table 12-14.

See Section 12.6.5.3 for RVD limits used to prevent excessive rail stress.

Figure 12-16: Relative Vertical Displacement at Expansion Joints – Track Serviceability

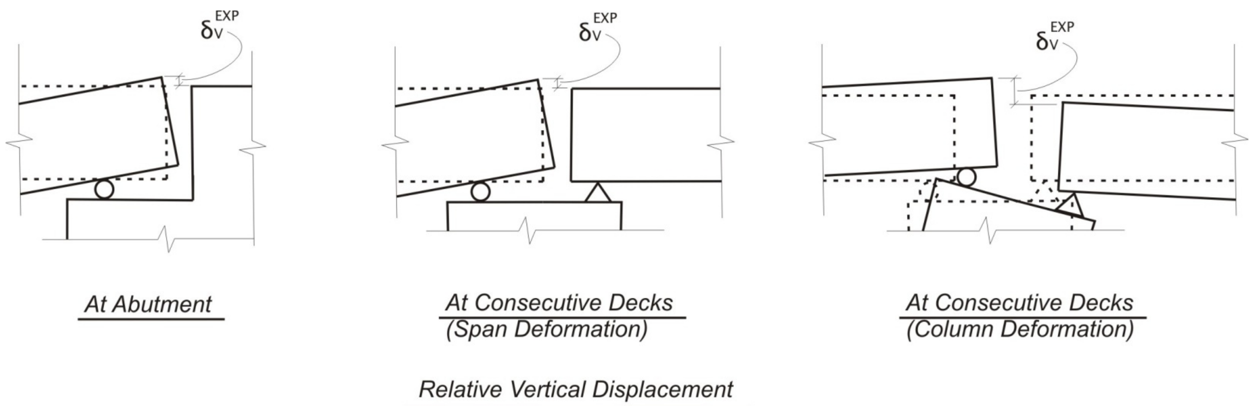


Table 12-14: Relative Vertical Displacement at Expansion Joints Limits – Track Serviceability

Group	δ_V^{EXP} (inch)
1a	0.25
1b	0.25
2	-
3	-

12.6.4.9 Relative Transverse Displacement at Expansion Joints – Track Serviceability

Relative transverse displacements (RTD) at structural expansion joints, δ_T^{EXP}, are limited in order to ensure track safety subject to shear key and lateral bearing deformation. Structural expansion joints between adjacent deck ends, and between deck ends and abutments shall be considered.

The relative transverse displacement at expansion joints (δ_T^{EXP}), shown in Figure 12-17, shall not exceed the limits given in Table 12-15.

See Section 12.6.5.4 for relative transverse deflection limits used to prevent excessive rail stress.

Figure 12-17: Relative Transverse Displacement at Expansion Joints – Track Serviceability

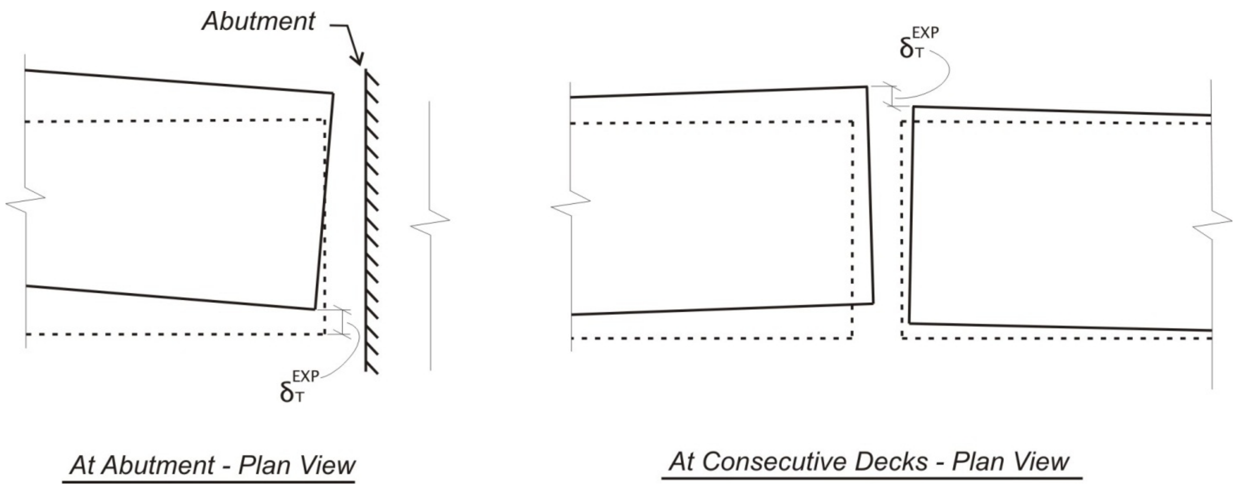


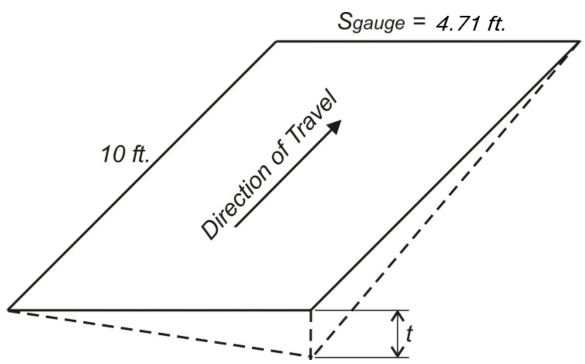
Table 12-15: Relative Transverse Displacement at Expansion Joints Limits – Track Serviceability

Group	δ_T^{EXP} (inch)
1a	0.08
1b	0.08
2	-
3	-

12.6.4.10 Deck Twist Limits

The deck twist, t, is defined as the relative vertical deck displacment of a given bogie contact point from a plane defined by the remaining three bogie contact points on a track gauge of 4.71 feet over a bogie length of 10 feet, see Figure 12-18. Deck twist limits ensure that the four wheel contact points of a bogie are not too far from a plane.

Figure 12-18: Deck Twist Diagram



Maximum deck twist (t_{max}) below tracks shall not exceed the limits given in Table 12-16.

Table 12-16: Deck Twist Limits

Group	t_{max} (inches / 10 feet)
1a	0.06
1b	0.06
2	0.17
3	0.17

12.6.5 Rail-Structure Interaction Analysis

Rail-structure interaction analysis, using modified Cooper E-50 loading, shall be used to limit relative longitudinal, vertical, and transverse displacements at structural expansion joints, and axial rail stress. Rail-structure interaction analysis is required to limit rail stress and therefore minimize the probability of derailment due to rail fracture, Deformation limits and rail stress limits were developed considering the accumulation of displacement demands and rail bending stresses under the controlling load combinations.

For rail-structure interaction analysis, the flexibility of superstructure and substructure (i.e.: bearings, shear keys, columns, and foundations) shall be considered.

In order to avoid underestimating deformations and rail stress, a lower bound estimate of stiffness and an upper bound estimate of mass shall be used.

Details of rail-structure modeling requirements are given in Section 12.6.8.5.

12.6.5.1 Rail-Structure Interaction Load Cases

Rail-structure interaction load cases include the following:

- Group 4: $(LLRM + I)_2 + LF_2 \pm T_D$
- Group 5: $(LLRM + I)_1 + LF_1 \pm 0.5T_D + OBE$

Where:

$(LLRM + I)_1$ = single track of Modified Cooper E-50 (LLRM) plus impact

$(LLRM + I)_2$ = two tracks of Modified Cooper E-50 (LLRM) plus impact

I = vertical impact factor from LLRR

LF_1 = braking forces (where one track, apply braking) for LLV loading

LF_2 = braking and acceleration forces (apply braking to one track, acceleration to the other track) for LLV loading

T_D = temperature differential of ±40°F between rails and deck, applied to the superstructure.

OBE = Operability Basis Earthquake per *Seismic* chapter

Groups 4 and 5 are to provide relative longitudinal, vertical, and transverse displacement limits at expansion joints, and design for uplift at direct fixation rail. Groups 4 and 5 are also used to limit rail stresses, accounting for thermal effects (i.e. $\pm T_D$).

Modeling of non-linear track-structure interaction effects, as given in Section 12.6.8.5, is required to give realistic demands. Experience has shown that linear modeling of track-structure interaction is overly conservative.

For Group 5, non-linear time-history OBE analysis (i.e., non-linear rail-structure interaction) shall be used for design. $(LLRM + I)_1 + LF_1$ may be idealized as a set of stationary load vectors placed upon the structure in the most unfavorable position. See the *Seismic* chapter for additional OBE modeling requirements.

12.6.5.2 Relative Longitudinal Displacement at Expansion Joints

Relative longitudinal displacements (RLD) at structural expansion joints, δ_L^{EXP}, are limited in order to prevent excessive rail axial stress. Structural expansion joints between adjacent deck ends, and between deck ends and abutments shall be considered.

RLD at structural expansion joints, δ_L^{EXP}, has components due to both structural translation and structural rotation. For structural rotation, RLD is a function of distance from center of rotation to rail centroid. Therefore, δ_L^{EXP} shall be monitored relative to the original rail centroid location, and consist of structural movement alone. For δ_L^{EXP}, strains in the rail and rail slippage are not considered.

Limits to δ_L^{EXP} under Group 4 are the basis for initial proportioning of structures and to limit rail stress.

Limits to δ_L^{EXP} under Group 5 are to limit rail stress.

δ_L^{EXP}, consists of separate components:

- δ_{LF} = component due to acceleration and braking only, see Figure 12-19.
- δ_{LLRM+I} = component due to vertical train plus impact loads only, see Figure 12-20.
- δ_{OBE} = component due to OBE only (see Figure 12-21), comprised of:
  - $\delta_{OBE(L)}$ = longitudinal displacement subcomponent due to OBE.
  - $\delta_{OBE(V)}$ = rotation about vertical axis subcomponent due to OBE.
  - $\delta_{OBE(T)}$ = rotation about transverse axis subcomponent due to OBE.
  - $\delta_{OBE} = \delta_{OBE(L)} + \delta_{OBE(V)} + \delta_{OBE(T)}$
- δ_{TD} = component due to temperature differential (T_D) between superstructure and rail.

Figure 12-19: δ_{LF} Definition

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Figure 12-20: δ_{LLRM+I} Definition

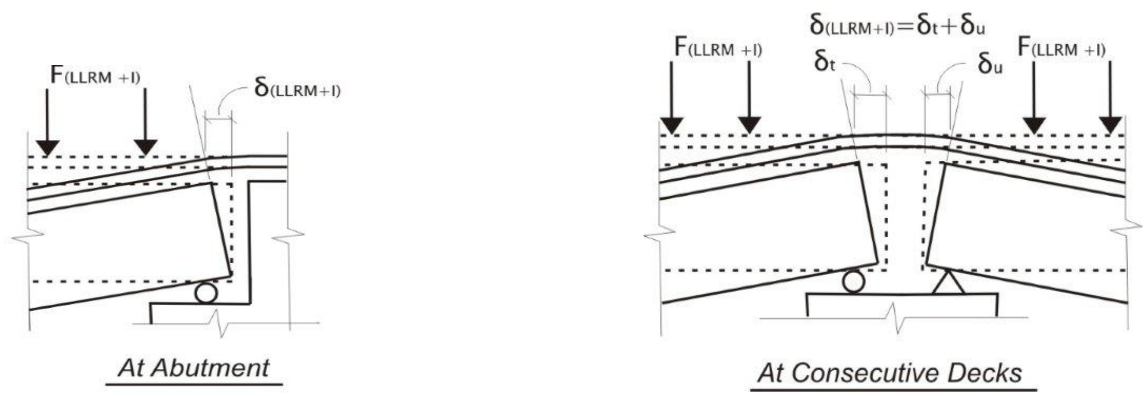
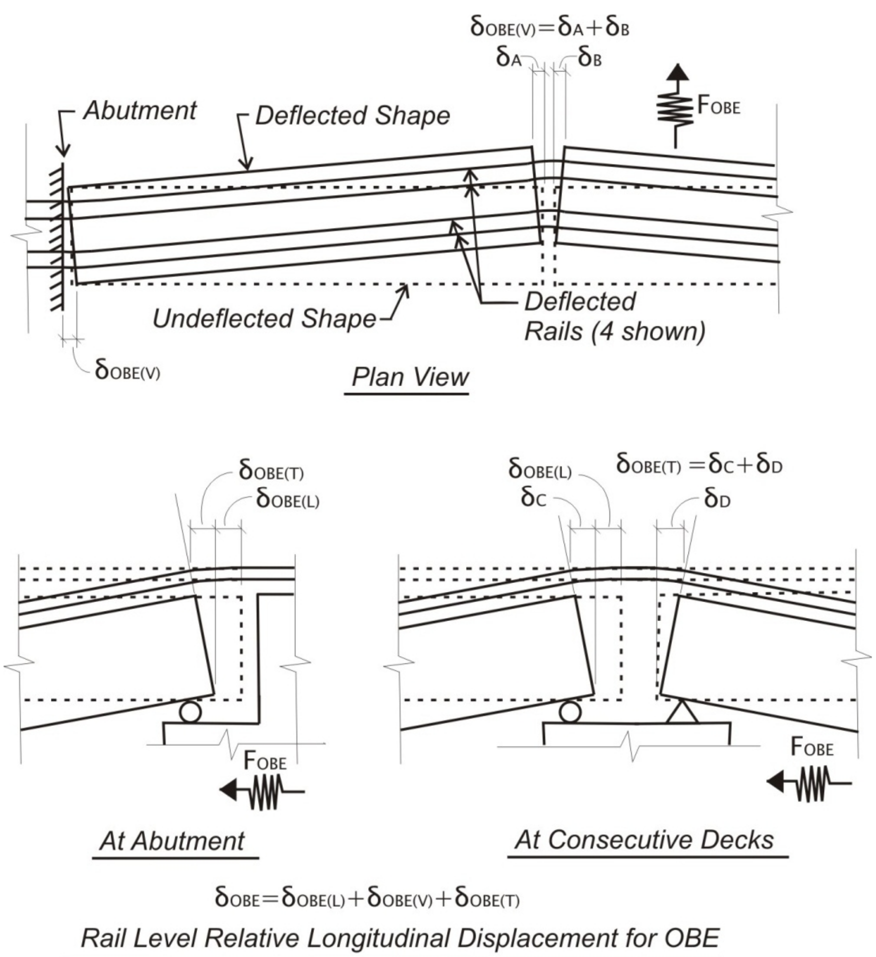


Figure 12-21: δ_{OBE} Definition



The RLD at expansion joints measured relative to the original rail centroid location (δ_L^{EXP}) shall not exceed the limits given in Table 12-17.

Note that in order to prevent having separate load cases for relative displacement and rail stress design, the expected temperature differential demands are added to the displacement limits. The temperature differential demands are dependent on the structural thermal unit (L_{TU}), which is defined as the point from fixed point of thermal expansion to the next adjacent fixed point of thermal expansion. The maximum L_{TU} shall not exceed 330 feet.

Table 12-17: Relative Longitudinal Displacement at Expansion Joints Limits

Group	δ_L^{EXP} (inch)
4	$1.0 + \delta_{TD,Expected}$
5	$2.33 + 0.5\delta_{TD,Expected}$

Where:

$\delta_{TD,Expected}$ = expected RLD measured relative to the original rail centroid location due to T_D loading per Section 12.6.5.1. For most structures, $\delta_{TD,Expected}$ can be approximated:

$$\delta_{TD,Expected} = \alpha(\Delta T)L_{TU}$$

Where:

α = coefficient of thermal expansion for the superstructure

ΔT = 40°F temperature differential per Section 12.6.5.1. (ΔT always positive for calculation of $\delta_{TD,Expected}$)

L_{TU} = length of structural thermal unit at a given expansion joint. If both sides of expansion joint are longitudinally free to displace, then both adjacent spans must be considered in L_{TU}. The maximum L_{TU} shall not exceed 330 feet.

For any structure which $\delta_{TD,Expected}$ cannot be approximated with the above equation, including Complex Structures per *Seismic* chapter, $\delta_{TD,Expected}$ shall be verified by monitoring rail-structure interaction models subject to T_D loading per Section 12.6.5.1.

12.6.5.3 Relative Vertical Displacement at Expansion Joints

Relative vertical displacement (RVD) at structural expansion joints, δ_V^{EXP}, are limited in order to prevent excessive rail bending stress. Structural expansion joints between adjacent deck ends, and between deck ends and abutments shall be considered.

The flexibility of the superstructure and substructure (i.e.: bearings, shear keys, columns, and foundations) shall be considered when calculating RVD.

The relative vertical displacement at expansion joints (δ_V^{EXP}), shown in Figure 12-22 shall not exceed the limits given in Table 12-18.

See Section 12.6.4.8 for RVD limits used to promote favorable track safety, passenger comfort, and track maintenance.

Figure 12-22: Relative Vertical Displacement at Expansion Joints

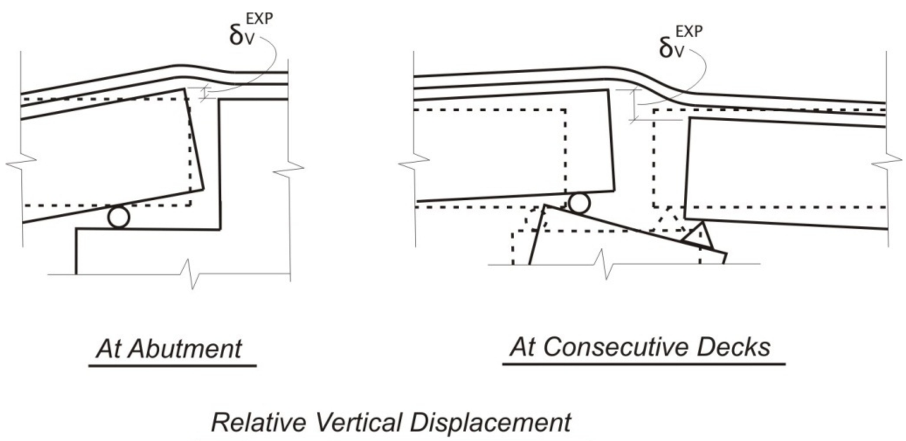


Table 12-18: Relative Vertical Displacement at Expansion Joints Limits

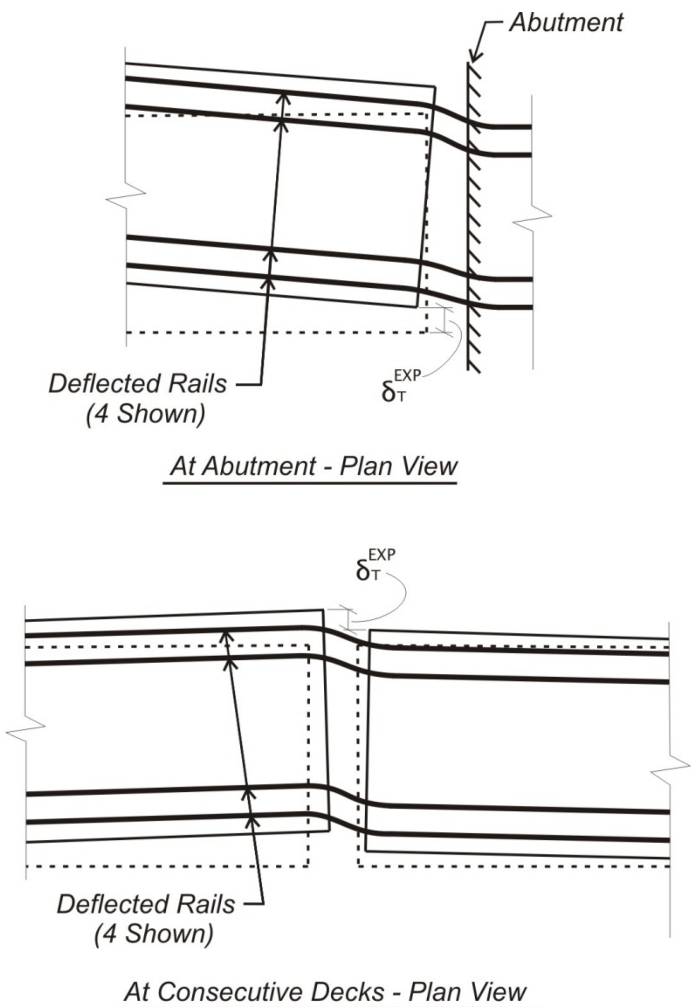
Group	δ_V^{EXP} (inch)
4	0.25
5	0.50

12.6.5.4 Relative Transverse Displacement at Expansion Joints

Relative transverse displacement (RTD) at structural expansion joints, δ_T^{EXP}, are limited in order to prevent excessive rail bending stress. Structural expansion joints between adjacent deck ends, and between deck ends and abutments shall be considered.

The relative transverse displacement at expansion joints (δ_T^{EXP}), shown in Figure 12-23, shall not exceed the limits given in Table 12-19.

Figure 12-23: Relative Transverse Displacement at Expansion Joints



See Section 12.6.4.9 for RTD limits used to promote favorable track safey, passenger comfort, and track maintenance.

Table 12-19: Relative Transverse Displacement at Expansion Joints Limits

Group	δ_T^{EXP} (inch)
4	0.08
5	0.16

12.6.5.5 Uplift at Direct Fixation Fasteners

For Groups 4 and 5, the direct fixation fastening system capacity, including the anchorage to supporting non-ballasted track, shall be designed to withstand calculated uplift force (F_{uplift}) by the factors of safety given in Table 12-20.

Table 12-20: Minimum Factor of Safety for Uplift on Direct Fixation Fasteners

Group	F_{uplift}
4	2.0
5	1.33

Specially designed fasteners with reduced vertical stiffness and/or increased uplift capacity may be required adjacent to structural expansion joints.

12.6.5.6 Permissible Additional Axial Rail Stress Limits

Permissible additional axial rail stress limits were developed considering total allowable rail stresses minus rail bending stresses due to vertical wheel loads and relative displacements at structural expansion joints. Additionally, the initial axial stress of the rail due to rail temperature and preheat during rail installation (per *Trackwork* chapter) was considered.

The permissible additional axial rail stress limits pertain to axial only rail stresses generated by track-structure interaction.

For rails on the bridge or aerial structure and adjacent abutment or at-grade regions, the permissible additional axial rail stresses (σ_{rail}) shall be per Table 12-21.

Table 12-21: Permissible Additional Axial Rail Stress Limits

Group	Range of σ_{rail}
4	-14 ksi ≤ σ_{rail} ≤ +14 ksi
5	-23 ksi ≤ σ_{rail} ≤ +23 ksi

Where negative is compression and positive is tension.

12.6.6 Dynamic Structural Analysis

Dynamic structural analysis of high-speed train passage (LLV) is required in order to determine resonancy induced dynamic impact (I_{LLV}) effects, and limit vertical deck accelerations. Maximum dynamic amplification occurs at resonance, when the structure's natural vertical frequency coincides with the frequency of axle loading.

All dynamic structural analysis of high-speed train passage using actual high-speed trains shall consider the flexibility of superstructure and substructure (i.e: bearings, columns, and foundations).

To avoid over or underestimating the resonant speeds, two conditions must be investigated:

- Condition #1 – lower bound estimate of stiffness and upper bound estimate of mass.

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- Condition #2 – upper bound estimate of stiffness and lower bound estimate of mass.

When evaluating vertical deck accelerations, Condition #2 – upper bound estimate of stiffness and lower bound estimate of mass, shall be investigated.

Modeling requirements for lower and upper bound estimates of stiffness and mass are given in Section 12.6.8.

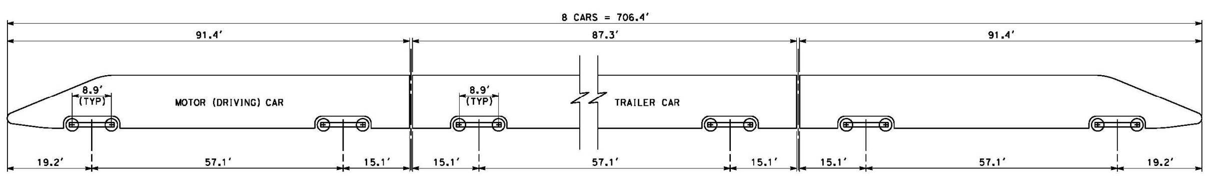
12.6.6.1 High Speed Train Loading (LLV)

Dynamic structural analysis of high-speed train passage shall consider representative trainsets (LLV), idealized as a series of moving vertical loads at specified axle and bogie spacings. Modeling of the train suspension system is not needed for dynamic structural analysis.

Five trainsets, shown in Figure 12-24 to Figure 12-28 collectively form LLV.

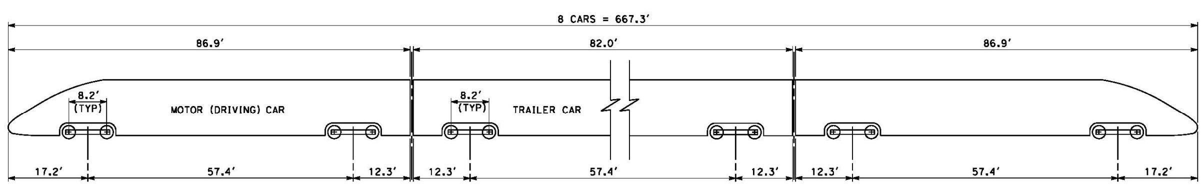
A full dynamic structural analysis using all five trainsets applies, subject to the suite of speeds given in Section 12.6.6.2.

Figure 12-24: Type 1



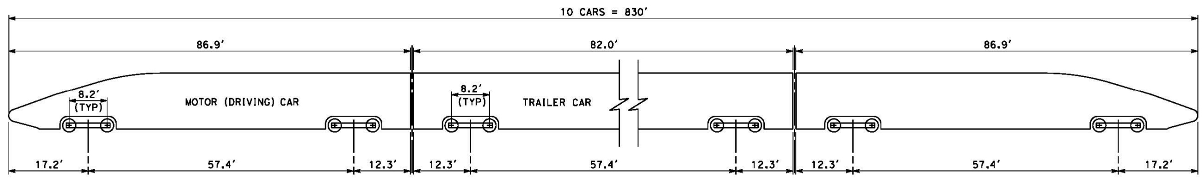
Maximum Axle Load = 18.7 tons Train Weight (Empty) = 510 tons

Figure 12-25: Type 2



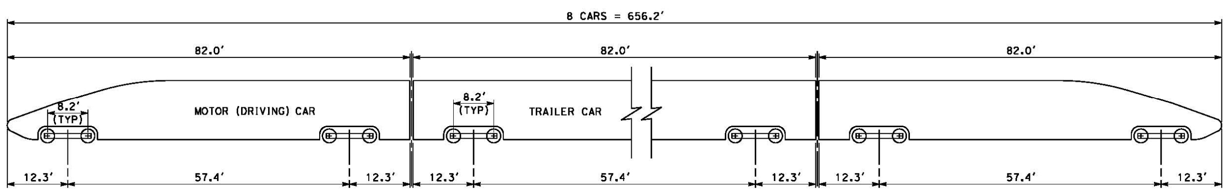
Maximum Axle Load = 16.5 tons Train Weight (Empty) = 529 tons

Figure 12-26: Type 3



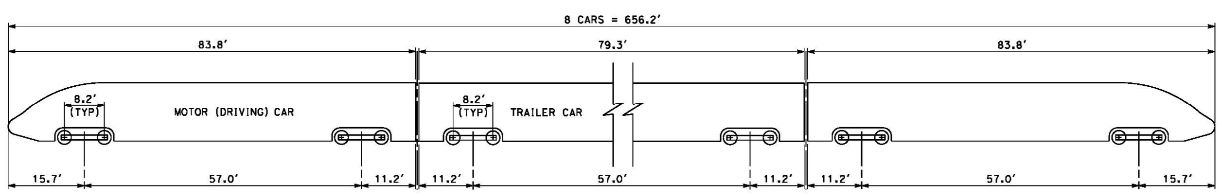
Maximum Axle Load = 12.95 tons Train Weight (Empty) = 500 tons

Figure 12-27: Type 4



Maximum Axle Load = 15.4 tons Train Weight (Empty) = 496 tons

Figure 12-28: Type 5



12.6.6.2 Train Speeds

A full dynamic structural analysis using all five trainsets applies, subject to the following suite of speeds:

- Speeds from 90 mph up to maximum speed of 1.2 times the line design speed (or 250 mph, whichever is less), by increment of 10 mph.
- Smaller increments of 5 mph for ±20 mph on each side of the first two resonant speeds.

A. Resonant Speeds

For simple spans, resonant speeds may be estimated by:

$V_i = n_o d/i$,

Where:

V_i = resonant speeds,

n_o = first natural frequency of vertical deflection

d = characteristic wheel spacing, see Figure 12-29

i = resonant mode numbers (e.g.: 1, 2, 3, 4, …)

Figure 12-29: Characteristic Wheel Spacing, d

For structures not consisting of simple spans, resonant speeds shall be determined by the dynamic structural analysis model.

B. Cancellation Speeds

In addition to resonance, cancellation effects also contribute to the overall dynamic response of elevated structures. For simple spans, cancellation speeds may be estimated by:

$$V_i = \frac{2\eta_o L}{2i - 1},$$

Where:

V_i = cancellation speeds,

n_o = first natural frequency of vertical deflection

L = simple span length

i = cancellation mode numbers (e.g.: 1, 2, 3, 4, …)

When L/d = 1.5, an optimal design condition exists for which the first mode of resonance aligns with the second mode of cancellation. In this condition, the primary dynamic residual response generated by repeated axle loads can be suppressed. Due to uncertainities associated with the service life of the structure, it may be unrealistic to design a given structure solely for a single characteristic wheel spacing. Nevertheless, optimal span lengths for potential trainsets shall be considered for design.

For more complex structures, the interaction between resonant and cancellation speeds may not be readily apparent and shall be investigated by a more detailed dynamic structural analysis.

12.6.6.3 Dynamic Impact Factors

For the high-speed trainsets (LLV), the dynamic model shall be used to determine the dynamic impact factors (I_{LLV}).

To determine (I_{LLV}), the maximum dynamic response value, ξ_{dyn} shall be found for each structural response for single track loading (LLV) over the range of speeds given in Section 12.6.6.2.

Compared against the corresponding static response value, ξ_{stat}, the dynamic impact factor is:

$$I_{LLV} = \max\left[\frac{\xi_{dyn}}{\xi_{stat}}\right]$$

12.6.6.4 Vertical Deck Acceleration

Vertical acceleration of bridge and aerial structure decks are limited to avoid reduction in wheel contact, and passenger discomfort.

When evaluating vertical deck accelerations, an upper bound estimate of stiffness and lower bound estimate of mass, shall be considered.

Vertical acceleration of bridge and aerial structure decks shall be found for single track loading (LLV) over the range of train speeds given in Section 12.6.6.2.

The maximum vertical deck acceleration shall be limited to 16.1 ft/s^2 (0.50g).

Note that this pertains to accelerations at the top of structural deck. For acceleration limits to be experienced within the train car body, see Section 12.6.7.

12.6.7 Dynamic Vehicle-Track-Structure Interaction Analysis

Should a structure fall within the recommended vertical frequency range (Section 12.6.3.1), then dynamic vehicle-track-structure interaction (VTSI) analysis shall not be required.

Should a structure fall outside of the recommended vertical frequency range (Section 12.6.3.1), then dynamic VTSI shall be required.

For Complex Structures per *Seismic* chapter, dynamic VTSI analysis may be required, as determined by the approved Seismic Design and Analysis Plan.

For typical structures, limiting the vertical, transverse, and torsional frequencies of the span, span deflections, relative displacements between spans, expansion joint widths, and deck acceleration provides sufficient guidance for track safety and passenger comfort. However, an advanced VTSI analysis is required for structures operating outside the known limits of acceptable performance, or structures with untested design concepts.

The purpose of VTSI analysis is to verify track safety and passenger comfort by considering the interaction between the vehicle, track, and structure.

Track safety depends primarily upon the contact forces between the rail and the wheel. The ratio of lateral to vertical forces (L/V ratio) is typically used as the primary indicator of derailment. In addition, the magnitudes of lateral and vertical forces imparted by the wheel to the rail must be controlled.

Passenger comfort depends primarily upon the the accelerations experienced within the train car body during travel on and off bridge or aerial structures.

12.6.7.1 Dynamic Train-Structure Interaction Analysis Requirements

For dynamic VTSI, both a dynamic structural model and dynamic trainset models shall be used. The interaction of the structure and trainset models shall be considered in either a coupled or iterative method.

Details of structural modeling requirements are given in Section 12.6.8.

Due to uncertainty of trainset selection, multiple trainset models shall be proposed for dynamic VTSI. Each of the dynamic trainset models shall be consistent with characteristic loading of LLV trainsets as defined in Section 12.6.6.1, and consider the mass, stiffness, and damping characteristics of the wheels, bogies, suspension, and body.

It has been shown that vehicle response is highly sensitive to track irregularities. For dynamic VTSI analysis, random track irregularities shall be considered directly in the VTSI model. Random theoretical irregularities shall be developed for FRA Track Classes using a power spectral density function which may be distributed into the time domain by applying the spectral representation method.

Dynamic VTSI analysis shall consider a series of speeds ranging from a minimum of 90 mph up to maximum speed of 1.2 times the line design speed (or 250 mph, whichever is less).

Dynamic VTSI analysis shall consider single track (i.e., one trainset) loading only.

For the dynamic VTSI analysis, a sufficient number of cars shall be used to produce maximum load effects in the longest span of the structure. In addition, a sufficient number of spans within a long viaduct structure shall be considered to initiate any resonance effects in the train suspension.

12.6.7.2 Dynamic Track Safety Criteria

Dynamic track safety criteria shall not exceed the limits given in Table 12-22 for any trainset across the required speed range.

Table 12-22: Dynamic Track Safety Limits

Parameter	Dynamic Track Safety Criteria
Maximum Single Wheel L/V Ratio	$L/V_{wheel} \leq 0.80$
Maximum Truck Side L/V Ratio	$L/V_{truck\ side} \leq 0.6$
Minimum Single Wheel Dynamic Vertical Load	$V_{wheel,dynamic} \geq 0.15*V_{wheel,static}$
Maximum Net Axle Dynamic Lateral Force	$L_{axle,dynamic} \leq 0.40*V_{axle,static} + 5$ kips

Where:

L/V_{wheel} = Ratio of lateral forces to vertical forces exerted by a single wheel on the rail

$L/V_{truck\ side}$ = Ratio of lateral forces to vertical forces exerted by any one side of a truck (bogie) on the rail

$V_{wheel,dynamic}$ = Dynamic vertical wheel reaction

$V_{wheel,static}$ = Static vertical wheel load

$L_{axle,dynamic}$ = Dynamic lateral axle reaction

$V_{axle,static}$ = Static vertical axle load

12.6.7.3 Dynamic Passenger Comfort Criteria

The maximum lateral acceleration within the car body is limited to 1.6 ft/s^2 (0.05 g) for any trainset across the required speed range.

The maximum vertical acceleration within the car body is limited to 1.45 ft/s^2 (0.045 g) for any trainset across the required speed range.

12.6.8 Modeling Requirements

The following modeling requirements for static and dynamic analysis of high-speed train bridge and aerial structures are required for project-wide consistency.

12.6.8.1 Model Geometry and Boundary Conditions

The model shall represent the bridge or aerial structure's span lengths, vertical and horizontal geometries, column heights, mass and stiffness distribution, bearings, shear keys, column or abutment supports, and foundation conditions.

For isolated bridges, with no adjacent structures, the model shall represent the entire bridge including abutment support conditions.

For repetitive aerial structure viaducts with simply supported spans the model shall have a minimum of 20 spans. Boundary conditions at the ends of the model shall represent the stiffness of any adjacent spans or frames.

For repetitive aerial structure viaducts with continuous span frames (i.e., each frame consists of multiple spans with moment transfer between the deck and columns), the model shall have a minimum of 5 frames. Boundary conditions at the ends of the model shall represent the stiffness of adjacent spans or frames.

Soil springs at the foundations shall be developed based on reports defined in the *Geotechnical* chapter.

For modeling of earthern embankments or cuts at bridge approaches, see Section 12.6.8.7.

12.6.8.2 Model Stiffness

Structural elements shall be represented by the appropriate sectional properties and material properties.

For frequency analysis and dynamic structural analysis, and dynamic VTSI analysis, both upper and lower bound estimates of stiffness shall be considered.

For track serviceability and rail structure interaction analysis, a lower bound estimate of stiffness shall be considered.

For steel superstructure and column members:

- Upper bound stiffness: full steel cross sectional properties, and expected material properties (larger than nominal specified per CBDS) shall be used.

- Lower bound stiffness: reduced steel cross sectional properties considering shear lag effects if necessary, and nominal material properties shall be used.

For reinforced, pre-stressed, and post-tensioned concrete superstructure members:

- Upper bound stiffness: full gross bending inertia, I_g, and modulus of elasticity corresponding to expected material properties (1.3x nominal) per CSDC shall be used. Consideration shall be made for composite action of the superstructure with non-ballasted track, barriers or derailment walls when determining upper bound bending inertias.

- Lower bound stiffness: effective bending inertia, I_{eff}, per CSDC, and modulus of elasticity corresponding to nominal material properties shall be used.

For concrete column members:

- Upper bound stiffness: full gross bending inertia, I_g, and modulus of elasticity corresponding to expected material properties (1.3x nominal) per CSDC shall be used.

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- Lower bound stiffness: cracked bending inertia, I_{cr}, per CSDC, and modulus of elasticity corresponding to nominal material properties shall be used.

As an alternative to using I_{cr} per CSDC, an effective bending inertia, I_{eff}, which considers the maximum moment demand, M_a, and the cracking moment, M_{cr}, may be used in accordance with AASHTO. Also, a moment-curvature representation of the column stiffness may be used.

12.6.8.3 Model Mass

For frequency analysis, dynamic structural analysis, and dynamic VTSI analysis, both upper and lower bound estimates of bridge mass shall be considered.

For track serviceability and rail structure interaction analysis, an upper bound estimate of bridge mass shall be considered.

For structural dead load (DC) mass, the material unit weights per Section 12.5 shall be used as the basis for design. For the upper bound mass estimate, unit weights shall be increased by a minimum of 5 percent. For the lower bound mass estimate, unit weights shall be reduced by a minimum of 5 percent.

For superimposed dead load (DW), upper and lower bound mass estimates shall be considered.

12.6.8.4 Model Damping

When performing OBE time history analyses for track serviceability and rail-structure interaction analysis, damping per *Seismic* chapter shall be used.

When performing dynamic structural analysis, the peak structural response at resonant speed is highly dependent upon damping. The damping values in Table 12-23 shall be used.

Table 12-23: Damping Values for Dynamic Model

Bridge Type	Percent of Critical Damping
Steel and composite	0.5%
Pre-stressed, post-tensioned concrete	1.0%
Reinforced concrete	1.5%

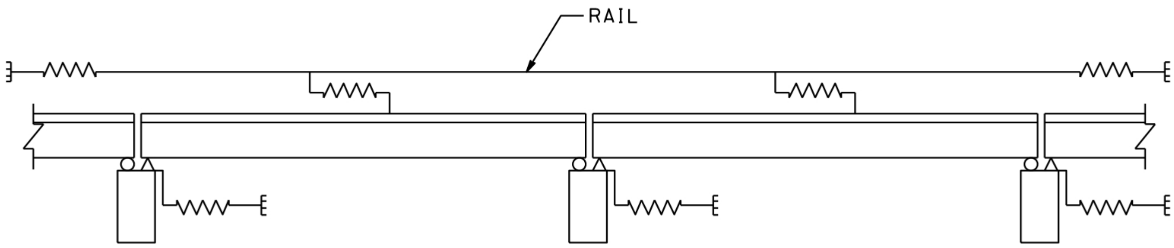
The damping may be increased for shorter spans (< 65 feet), with supporting evidence by Designer.

When performing dynamic structural analysis using actual high-speed trains, soil damping shall be considered in accordance with the Geotechnical reports described in the *Geotechnical* chapter.

12.6.8.5 Modeling of Rail-Structure Interaction

Longitudinal actions produce longitudinal forces in the continuous rails. These forces are distributed to the bridge and aerial structures in accordance with the relative stiffness of the non-ballasted track and fasteners, articulation of the structural system, and stiffness of the substructure, see Figure 12-30 for a schematic rail-structure interaction model.

Figure 12-30: Rail-Structure Interaction Model



Rail-structure interaction may govern the:

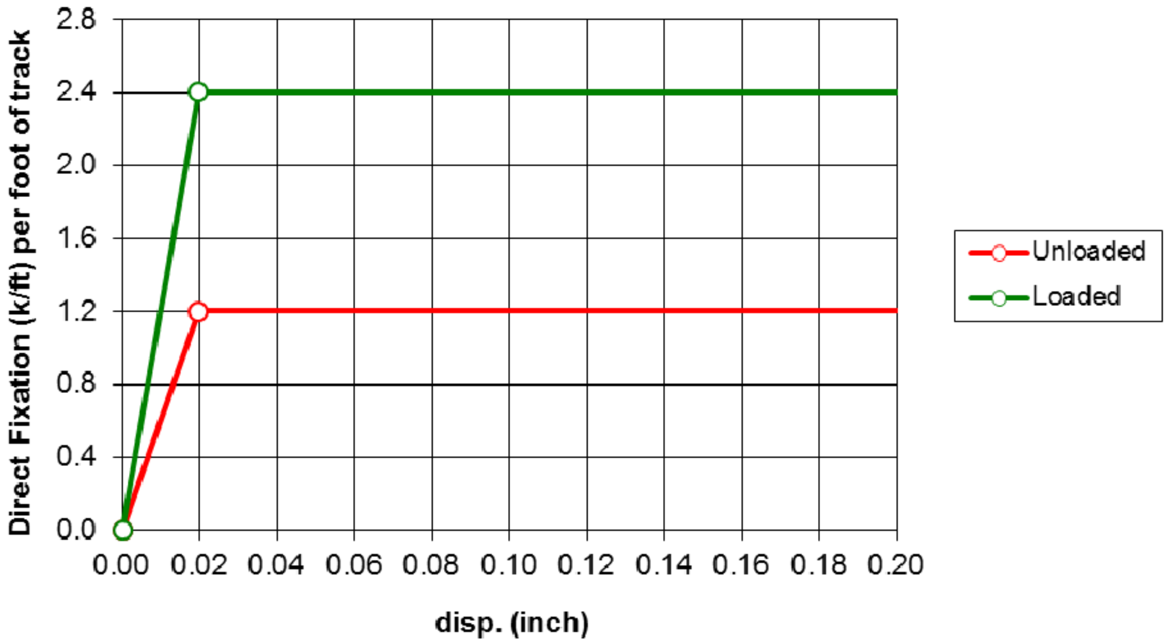
- Location and distance between bridge expansion joints.
- Stiffness of the bridge superstructure.
- Stiffness of the supporting columns and foundations.

Rail-structure interaction shall be performed for all structures using either static or dynamic models. In addition, the model shall include the stiffness of the rails appropriately located upon the superstructure, and longitudinal bi-linear coupling springs between the track and superstructure over the length of the model.

For purposes of this analysis, the rail section shall be 141 RE per AREMA. In the event that another rail section is considered, a special rail-structure interaction analysis is required per Section 12.6.8.6.

Fastener restraint is nonlinear to allow slippage of the rail relative to the track support structure. The bi-linear coupling springs shall represent non-ballasted track with direct fixation fasteners (see Figure 12-31) between the rails and superstructure on a per track basis. This relationship represents a pair of fasteners with 1.35 kip (6 kN) unloaded longitudinal restraint at 27-inch spacing.

Figure 12-31: Non-Ballasted Track with Direct Fixation Fasteners: Bi-linear Coupling Springs



Assumed fastener properties represent a uniform distributed longitudinal restraint of 1.2 k/ft (unloaded) per foot of track. In practice, variations in fastener spacing may be required to accommodate structural expansion joints, deck skew, or other geometric constraints.

Uniform longitudinal restraint shall be verified using the following uniformity criteria:

Distributed longitudinal restraint calculated for fastener locations over any 10 ft. length of track along the structure shall be within +/-20% of the assumed uniform bi-linear coupling relation.

For aerial structures that meet the uniformity criteria, but not consistent with Figure 12-31, the structure shall be considered to have a nonstandard fastener configuration (NSFC). These structures require an approved design variance and special rail-structure interaction analysis per Section 12.6.8.6.

For aerial structures that do not meet the uniformity criteria, the structure shall be considered to have a non-uniform fastener configuration (NUFC). These structures require an approved design variance and a special rail-structure interaction analysis per Section 12.6.8.6.

The total number of longitudinal bi-linear coupling springs per each span shall not be less than 10 and the spacing between the springs shall not be more than 10 feet.

For vertical stiffness of fasteners, 4000 k/ft per foot of track (pair of rails) shall be used. For purposes of evaluating this design criteria, constant vertical stiffness shall be used to model fastener compression and tension (uplift).

For lateral (i.e., transverse) stiffness of fasteners, 450 k/ft per foot of track (pair of rails) shall be used.

12.6.8.6 Special Rail-Structure Interaction Analysis

Rail-structure interaction limits are developed considering typical fastener configurations on typical structures. For those systems that do not meet these assumptions, new limits must be developed using a refined analysis.

A special rail-structure interaction analysis shall be required for those structure and track designs requiring a design variance. Specific design variances requiring special rail-structure interaction analysis include, but are not necessarily limited to: designs requiring nonstandard fastener configurations (NSFC), non-uniform fastener configurations (NUFC), rail section other than RE 141, structures with thermal units (L_{TU}) greater than 330 feet, rail expansion joints (REJs), and ballasted track on aerial structures.

The Contractor shall identify and document structure types requiring special rail-structure interaction analysis as part of the Type Selection process described in Section 12.8.1.1. After completion of Type Selection and upon determination that the selected structure type requires a special rail-structure interaction analysis, the Contractor shall develop a Rail Stress and Fasteners Design and Analysis Plan (RSFDAP) as part of the design variance submittal. The RSFDAP shall formally identify elements requiring special consideration, including but not limited to: refined fastener properties, detailed temperature analysis, refined ballast/nonballasted properties, and rail expansion joint locations. A detailed proposal of analysis procedures used to verify track performance (including track safety, passenger comfort, track maintenance, and rail stress) shall be submitted as part of the RSFDAP.

Examples of special analysis required may include, but is not limited to: development of new rail-structure interaction limits, development of new analytical model elements, local rail stress modeling, site-specific temperature analysis, analysis of impacts to track maintenance, etc.

12.6.8.7 Modeling of Rail-Structure Interaction at Model Boundaries

Where an abutment occurs at the ends of bridges and aerial structures, the rails and coupling spring fastener elements shall be extended a distance of L_{ext} from the face of the abutment. At the model boundary (i.e., at L_{ext} from abutment), a horizontal boundary spring representing the rail/fastener system behavior shall be used. The boundary spring, which represents unloaded track, shall be elastic-perfectly plastic, with a elastic spring constant of k (k/ft) yielding at P_b (kips), which represents the maximum capacity of an infinite number of elastic fasteners.

The yielding of the boundary spring at P_b is a threshold value that should be checked throughout the track-structure interaction analysis. If at any point during the analysis the boundary spring yields at force P_b, L_{ext} should be increased and the analysis should be repeated until elastic boundary spring behavior is verified.

The boundary spring behavior depends on the at-grade track type and fasteners. Values of k, P_b, and L_{ext} are given for a variety of direct fixation fasteners and track types in Table 12-24. Note that the minimum recommended values of L_{ext} are dependent on the average span length of the bridge or aerial structure (denoted L_{avg}):

$$L_{avg} = \frac{(L_1 + L_2 + ... + L_n)}{n}$$ = the average span length

Table 12-24: Minimum Recommended Track Extension and Boundary Spring Properties

Non-Ballasted Track (fasteners yield at 0.02 inches)			
Yield Load per foot of non-ballasted track	**k (kips/ft)**	**P_b (kips)**	**Min. Recommended L_{ext} (feet)**
1.20 kips per foot of track [1.35 kips (6 kN) fasteners @ 27" o.c.]	24,200	40.3	$0.1L_{avg}$ + 350
1.80 kips per foot of track [2.02 kips (9 kN) fasteners @ 27" o.c.]	29,600	49.3	$0.1L_{avg}$ + 275
2.40 kips per foot of track [2.70 kips (12 kN) fasteners @ 27" o.c.]	34,200	57.0	$0.1L_{avg}$ + 240
Ballasted Track (fasteners yield at 0.08 inches)			
Yield Load per foot of ballast	**k (kips/ft)**	**P_b (kips)**	**Min. Recommended L_{ext} (feet)**
1.37 kips/ft of track	12,900	86.0	$0.1L_{avg}$ + 310

In the event that an additional bridge or other elevated structure is located within the L_{ext} model boundary distance from the face of an earthen abutment, the additional structure (including the loads and modeling requirements presented in this section) shall also be included in the track-structure analysis model.

Assumptions used to develop Table 12-24 are expected to apply for the majority of elevated structures and viaducts, which are assumed to be in simply-supported configuration with uniform distribution of fasteners. For alternative structure and fastener configurations, additional investigation shall be required to appropriately define the model boundary.

12.6.8.8 Modeling of Earthen Embankments or Cuts at Bridge Approaches

Where applicable under rail-structure interaction Group 5 load cases, the vertical and lateral stiffness of slab or ballasted track upon earthen embankments or cuts shall be determined to accurately predict relative displacements at abutment expansion joints, and rail stress at the abutment and at-grade regions.

For vertical stiffness of track upon earthen embankment or cuts, a minimum value of 350 pci shall be used in accordance with AREMA subgrade requirements.

For lateral (i.e., longitudinal and transverse) stiffness of track upon earthen embankments or cuts, consideration of embankment flexibility, non-ballasted track or ballast tie embedment,

passive pressure, and friction shall be made in accordance with the Geotechnical reports described in the *Geotechnical* chapter.

OBE ground motions shall be applied concurrently at structural foundations and earthen embankments or cuts to prevent incompatibility between the vibrating structure and the relatively stationary track upon earthen embankment or cut. For tall embankments or specific soil types, lag times and/or amplification effects shall be considered for OBE ground motions in accordance with the Geotechnical reports described in the *Geotechnical* chapter.

12.7 Structural Design of Surface Facilities and Buildings

The static design of stations, surface facilities, buildings and ancillary structures shall conform to the requirements of CBC, AISC, and ASCE 7 whichever is applicable except as specified otherwise. The seismic design of stations, surface facilities, buildings, and ancillary structures that are primary structures shall conform to the requirements of CBC, AISC, and ASCE 7, whichever is applicable. In addition, the seismic requirements of the *Seismic* chapter shall apply.

For description of Primary and Secondary structures as well as seismic requirements, refer to the *Seismic* chapter.

Primary structures supporting HSTs shall meet the requirements of Section 12.5 for Permanent and Transient Loads for Structures Supporting HST. If such a facility has uses other than supporting or in addition to HSTs or other types of bridges it shall also meet the requirements of this Section 12.7. For foundation design, see the requirements in the *Geotechnical* chapter.

12.7.1 Load Requirements for Stations, Surface Facilities and Buildings

Elevated and at-grade station structures not supporting HSTs, as well as surface facilities and buildings, shall be subject to CBC requirements, with additional criteria specific to the HST.

Station platforms, mezzanines, and aerial pedestrian access ramps shall be subject to additional criteria specific to the CHSTP herein.

12.7.1.1 Dead Load and Superimposed Dead Load

Dead load and superimposed dead load shall include but not be limited to the following:

- Dead weight of structural members and architectural finishes,
- Dead weight of road surface and of backfill above the structures,
- Dead weight of surcharge loads,
- Dead weight of equipment and appurtenances.

Refer to Section 12.5 on Permanent and Transient Loads for Structures Supporting HST for the unit weights of materials.

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12.7.1.2 Train Load

Refer to Section 12.5 on Permanent and Transient Loads for Structures Supporting HST for the train loading.

12.7.1.3 Roof Load

Roof live load and reduction factors shall be in accordance with the CBC.

12.7.1.4 Floor Load

Floor live load shall be in accordance with the CBC with no reduction in floor live load, except for parking structures.

Station platforms and concourse areas shall be designed for a floor live load of 100 psf.

Emergency and maintenance walkways shall be designed for a floor live load of 100 psf.

Floor live loads on service walkways and sidewalks shall be designed for a live load of 100 psf, or a concentrated load of 2,000 pounds applied anywhere on the walkway and distributed over a 4 feet by 2 feet area.

The structural system supporting the access doors at street level shall be designed for a floor live load of 350 psf.

Storage area floor live loads shall be 100 psf.

Areas where cash carts are used shall be designed to accommodate a point live load of 350 pounds per wheel. Wherever station configuration requires that cash carts cross pedestrian bridges, bridges shall be designed to accommodate this live load.

Operations Control Centers shall be designed for a floor live load of 100 psf.

Equipment room floors for such uses as signals, communications, power, transformers, battery storage and fanrooms shall be designed for a minimum floor loading sufficient to support both 350 psf distributed load and a 2000 pounds concentrated load or the actual equipment weight located so as to produce the maximum load effects in the structural members.

Pump rooms, service rooms, storage space, and machinery rooms shall be designed for floor live load of 250 psf, to be increased if storage or machinery loads so dictate.

Stairways shall be designed for a floor live load of 100 psf or a concentrated load of 300 pounds on the center of stair treads, whichever is critical. Impact shall not be considered for stairways.

Maintenance buildings will require overhead cranes and crane rails or floor mounted hydraulic jacks to lift individual cars from trains. The car loads are unknown until a vehicle is selected. The Designer shall coordinate with the Authority to obtain design requirements for crane design.

12.7.1.5 Vehicular Load

Parking areas for automobiles shall be designed to a minimum load as specified in the CBC. Bus load shall be designed to carry HL-93 loading in accordance with AASHTO LRFD with Caltrans Amendments.

Gratings in areas that are subject to vehicular loading shall be designed to carry HL-93 loading.

12.7.1.6 Miscellaneous Loads

Pedestrian safety railings shall be designed to withstand a horizontal force of 50 pounds per linear foot applied at any angles to the top of the railing. The mounting of handrails and framing of members for railings shall be such that the completed handrail and supporting structure shall be capable of withstanding a load of at least 200 pounds applied in any direction at any point on the top rail. These loads shall not be combined with the 50 pounds per linear foot. For the design of structure components that support train loads and a walkway, the walkway live loads shall not be applied simultaneously with the train loads.

Stationary and hinged cover assemblies internal to HST facilities shall be designed for a minimum uniform live load of 100 psf or a concentrated live load of 1,000 pounds over a 2 feet by 2 feet area. Deflection at center of span under 100 psf load shall not be more than 1/8 inch.

Gratings in sidewalks and in areas protected from vehicular traffic shall be designed for a uniform live load (LL) of 300 psf.

12.7.1.7 Slipstream Effects from Passing Trains

Refer to Section 12.5.2.7 for slipstream effects from passing high-speed trains.

Where structural elements can also be subjected to wind load, loading due to the slipstream effects from passing trains shall be considered to occur in combination with wind load.

Where trains are enclosed between walls and with a ceiling and deck, the design requirements for tunnels shall be met (see *Tunnels* chapter) including the following:

- Minimum cross section area of the through trackway
- Evacuation
- Fire/Life Safety
- Medical Health Criteria

In addition, transient air pressure analyses (as in a tunnel ventilation analysis) shall be used to determine the maximum transient air pressure acting on the walls and ceiling. These pressures shall be used for design of those elements such as uplift of ceilings or lateral pressure on walls and doors.

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12.7.1.8 Seismic Design for Stations and Ancillary Facilities

Seismic design of primary and secondary structure facilities as defined in the *Seismic* chapter shall comply with the requirements of the *Seismic* chapter.

12.7.1.9 Collision Loads in Stations

Columns in stations shall be classified into three groups, according to the following criteria:

- GROUP A – This group consists of columns where the clearance measured from the TCL to face column and relevant conditions are as follows:
  - ≥ 16.5 feet
  - < 16.5 feet and within the station platform area provided that the platform is of massive construction and the platform edge is at least 1.25 feet above the level of the nearest rail.

  No collision impact forces shall be applied.
  - GROUP B – GROUP B columns are those located in a row of columns which run adjacent and parallel to the HST track and which do not meet the criteria of GROUP A. Columns in the row are classified as GROUP B, with the exception of the first and last ones. The column row shall include a column protection wall throughout its length. . The performance for this loading is a no collapse requirement.
  - The column protection wall shall comprise a lower guide wall together with an upper guide beam as shown in Figure 12-32. Due to the presence of the column protection wall, the GROUP B columns need not withstand full face collisions, but only grazing impacts by trains that have already been derailed. The lower guide wall and the upper guide beam shall be designed to withstand collision impact loads.
  - Columns and column protection walls shall be designed for one of the following horizontal collision impact loads, whichever produces the most adverse effect:
  - Columns shall be designed to resist a 900 kip force parallel with the TCL acting together with a 400 kip force at 90 degrees to the TCL, both 4 feet above low rail level and 225 kip force at 90 degrees to the TCL, 10 feet above TOR.
  - Lower guide wall shall be designed to resist a 900 kip force parallel with the TCL acting together with a 400 kip force at 90 degrees to the TCL, both 3.5 feet above top of low rail.
  - Upper guide beam shall be designed to resist a 350 kip force at 90 degrees to the TCL, acting 10 feet above top of low rail.
- GROUP C – Group C consists of the first and last columns in a row that do not belong to Group A or Group B.
  - The collision loads for each group of columns, as indicated above, are as follows:

- o Columns shall be designed for one of the following horizontal collision impact loads, whichever produces the most adverse effect. The performance for this loading is a no collapse requirement. A 2250 kip force parallel with the TCL acting together with an 800 kip force at 90 degrees to the TCL, both acting 4 feet above top of low rail

- o A 225 kip force at 90-degree to the TCL, acting 10 feet above low rail level

Alternatively, a protection device designed to resist the GROUP C impact loads shall be provided at the open face of the column as shown in Figure 12-33. The column in this figure shall be designed for the GROUP B column impact loads.

Figure 12-32: Collision Loads for Each Group of Columns

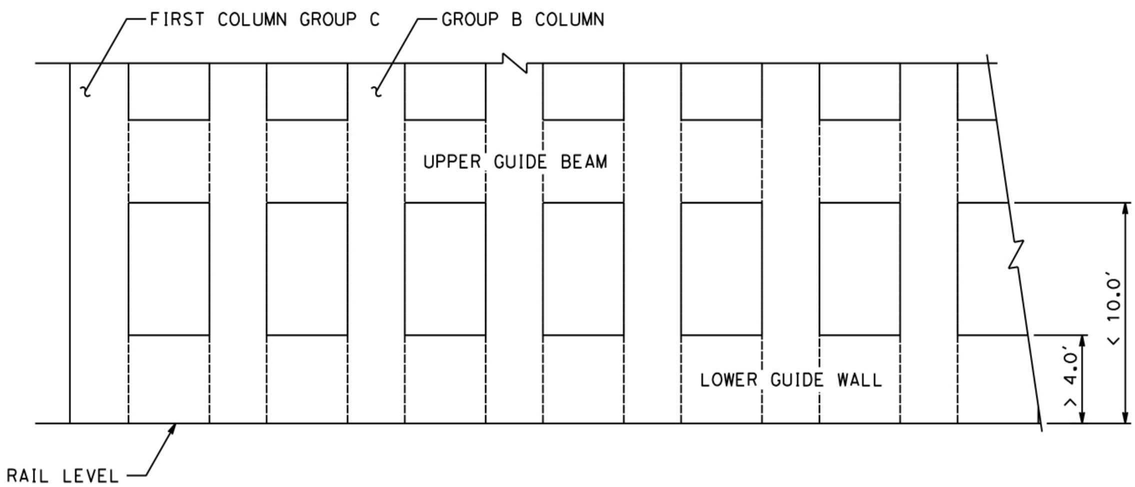
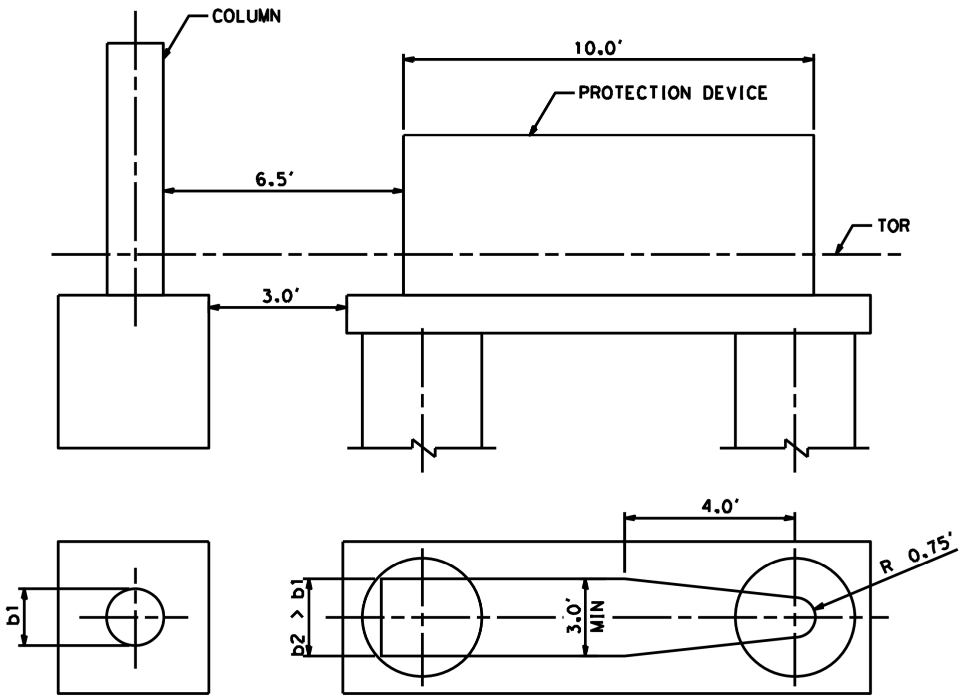


Figure 12-33: Protection Device



12.7.1.10 Collision Loads on Platforms

Platforms shall be designed to withstand a horizontal collision impact load of 225 kips applied at 90-degree to the TCL of the nearest track located anywhere along the platform.

A 1-foot-wide void shall be provided around columns that are within platform areas to prevent transfer of collision loads to the column.

12.7.1.11 Wind Loads

Wind loads including both windward and leeward sides of buildings and other structures shall be in accordance with the provisions of CBC, with $I_w = 1.15$.

12.7.1.12 Effects of Temperature, Shrinkage and Creep

Effects of temperature, shrinkage and creep shall be considered for structures above ground, as per requirements of the CBC.

12.7.1.13 Frequency and Vibration Limits

Station structures shall be designed to meet the following requirements for pedestrian comfort:

- The comfort criteria shall be defined in terms of maximum acceptable acceleration of any part of the station platform or deck occupied by the public. The following accelerations are the recommended maximum values for any part of the station platform or deck:

  - 2.3 ft/s^2 for vertical vibrations
  - 0.7 ft/s^2 for horizontal vibrations
  - 1.3 ft/s^2 for exceptional crowd conditions vertical vibrations
- A verification of the comfort criteria shall be performed if the fundamental frequency of the deck is less than:
  - 5 Hz for vertical vibrations
  - 2.5 Hz for horizontal (lateral) and torsional vibrations. Transverse frequency analysis shall consider the flexibility of superstructure only, excluding the flexibility of bearings, columns, and foundations, assuming the supports at the ends of the span are rigid.

12.7.2 Foundations for Equipment Enclosures

Refer to the *Traction Power Supply System* chapter, *Automatic Train Control* chapter, and the *Communications* chapter.

For other equipment facilities, follow geotechnical recommendations and the provisions of CBC for design of foundations.

12.7.3 Foundations for Utility Equipment

Foundations for utility equipment shall comply with the requirement of CBC and in addition meet the requirements of the individual utility.

12.8 Design Considerations for Bridges and Aerial Structures

Unless otherwise specified, aerial structure design of HST structures as well as highway bridge structures shall be performed in accordance with AASHTO LRFD with Caltrans Amendments.

Design of HST aerial structures shall satisfy criteria that exceed those of highway and normal rail bridges because of the following:

- Particular effects which are critical in HST aerial structures:
  - Frequency of repetition (fatigue of materials)
  - Repetitive load applications (dynamic structural response)
  - Interaction of track and structure
- Riding comfort criteria
- High operating demands (life time of structure)

- Limited hours available for inspection, maintenance and repair.

To meet the above mentioned criteria, HST aerial structures shall be designed to conform with the following characteristics:

- Small deflections and good resilience to dynamic responses to ensure passenger safety and a very high level of comfort
- Low probability of resonance
- Conceptual simplicity and standardization for ease of construction, schematic quality control, fast track construction and higher maintenance reliability
- Reduction of environmental noise and vibration impact.

12.8.1 General Design Requirements

12.8.1.1 Type Selection

The type of bridges selected for design and construction shall be selected in a type selection process. This process is best described in the requirements of the Caltrans OSFP Information and Procedures Guide. The Authority's preference for type is prestressed concrete single box girders carrying two tracks for main line aerial trackways and structures. Box girders can be precast, precast segmental, or cast in-place, cast-in-place span by span or other similar types of construction. For specific locations, thru girders or thru trusses constructed by piece or incrementally launched may be more appropriate. The Type Selection shall include seismic considerations, foundation recommendations, aesthetics review, traffic maintenance (both highway and rail), drainage considerations and intrusion protection. Included with or in the Type Selection Report shall be all of the following that apply to the specific bridge or aerial structure:

- Type Selection Memo (see Caltrans OSFP Information and Procedures Guide)
- Hydrology and Hydraulics reports
- Aesthetics Design and Review Report
- Geotechnical Engineering Design Report
- Seismic Design and Analysis Plan (*Seismic* chapter)
- Rail Stress and Fastener Design and Analysis Plan (Section 12.6.8.6)
- Complex and Non-Standard Aerial Structures Load Path Report (Section 12.8.7)

If rail expansion joints are considered the variance process should start at Type Selection.

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For isolated structures and the structures not in the main line, and highway bridges, structure type selection shall follow the requirements of the Caltrans OSFP Information and Procedures Guide. The Type Selection shall be coordinated with the Authority to determine and identify any constraints that may control the design that are not listed in these Design Criteria.

12.8.1.2 Clearances

Clearances requirements are specified in the *Trackway Clearances* chapter.

12.8.1.3 Water Crossings

Hydraulic requirements for bridge drainage and requirements for water crossings are specified in the *Drainage* chapter.

12.8.1.4 Deck Arrangement

The arrangement of deck features shall conform to the requirements presented in the Standard and Directive Drawings.

12.8.1.5 Material Requirements

A. Concrete Requirements

The minimum 28-days concrete compressive strength in aerial structures shall be as follows:

- For piles, shafts, and footing reinforced concrete cast-in-place structures, f'c = 4,000 psi.
- For above ground reinforced concrete cast-in-place structures, f'c = 5,000 psi.
- For cast-in-place prestressed concrete, f'c = 6,000 psi.
- For precast prestressed members, f'c = 6,000 psi.
- Lightweight concrete is not allowed in Primary Type 1 structures. It may be used in secondary concrete such as leveling or non-ballasted track concrete.

For design of cast-in-place piles and shafts, the nominal concrete strength shall not be greater than f’c = 4,000 psi

B. Reinforcing Steel

Reinforcing steel for concrete reinforcement including spiral reinforcement shall conform to ASTM A706/706M, Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement.

Plain wire for welded wire fabric shall comply with ASTM A82, Specification for Steel Wire, Plain, for Concrete Reinforcement.

C. Concrete Cover

Minimum concrete cover shall conform to AASHTO LRFD with Caltrans Amendments Table 5.12.3-1, with the following exceptions:

- Uncased drilled shafts: 6 inches
- Cased drilled shafts with temporary casing: 4 inches

D. Prestressing Steel

Prestressing steel shall conform to the requirements of ASTM A416/A416M, or ASTM A722. Prestressing strand or wire shall be low relaxation. Additional requirements follow:

- Only post-tensioning systems that utilize tendons fully encapsulated with grout within the anchorages and ducts are allowed.
- Embedded anchors for bars are permitted.
- Strand or tendon couplers are not permitted.
- Select the post-tensioning grout for use by the proper application either repair, horizontal, or vertical. Grout will be mixed with potable water.
- Grout
  - Only pre-packaged grout mixes designed for the specific application are permitted. The grout shall not contain aluminum or other components which produce hydrogen, carbon dioxide or oxygen gas.
  - Chemical testing of a fresh dry sample taken from a bag in each lot of prepackaged grout shall be performed to determine chloride concentrations in accordance with the following requirement. Total chloride ions shall be less than 0.08% measured by weight of cementious material according to ASTM C1152.
- Anchorages
  - Ensure that anchorages develop at least 95 percent of the actual ultimate tensile strength of the prestressing steel when tested in an unbonded state, without exceeding the anticipated set.
  - Design anchorages so the average concrete bearing stress is in compliance with AASHTO "Load and Resistance Factor Design (LRFD) Bridge Design Specifications."
  - Test and provide written certification that anchorages meet or exceed the testing requirements in the AASHTO "LRFD Bridge Construction Specifications".
  - Equip anchorages with a permanent grout cap vented and bolted to the anchorage. Provide wedge plates with centering lugs or shoulders to facilitate alignment with the bearing plate. Cast anchorages with grout outlets suitable for inspection from either the top or front of the anchorage. The grout outlet shall serve a dual function of grout outlet and post-grouting inspection access. The geometry of the grout outlets must facilitate being drilled using a 3/8-inch-diameter straight bit to facilitate endoscope inspection directly behind the anchor plate. Anchorages may be fabricated to facilitate both inspection locations or may be two separate anchorages of the same type – each providing singular inspection entry locations.

- Anchorages shall be protected with epoxy grout encapsulation with an elastomeric coating

- Ducts and Pipes
  - Do not use ducts manufactured from recycled material.
  - Use seamless fabrication methods to manufacture ducts.
  - Ferrous metal ducts shall not be used.
  - Precast segmental bridges with internal tendons shall use segmental duct couplers with 6 degrees of alignment allowance at all segment joints.

E. Structural Steel

Structural steel design for bridge-type structures shall meet the requirements of the AASHTO LRFD with Caltrans Amendments.

Structural Steel Shapes shall conform to ASTM A6. Additional properties are as follows:

Wide flange shapes:	ASTM A992
M-shapes, S-shapes, HP shapes:	ASTM A572
Angles, Channels:	ASTM A572
Rectangular and square hollow sections:	ASTM A500 Gr B (46 ksi)
Round hollow sections:	ASTM A500 Gr B (42 ksi)
Steel pipe:	ASTM A53 Gr B (35 ksi)
Plates, Bars:	ASTM A36 (36 ksi)
Bolts:	ASTM A325
Nuts:	ASTM A563
Washers:	ASTM F436

Welding of built up members and steel fabrications shall comply with AASHTO/AWS D 1.5

Welding of HSS sections and pipes shall comply with AWS D 1.1

Miscellaneous steel items shall be hot-dip galvanized after fabrication unless completely embedded in concrete and unless noted otherwise

Splice Locations – If splicing of a structural steel member is permitted, indicate the location of the splice. Such locations shall be at or near a cross section of minimum stress.

12.8.2 Design Loads and Effects

Aerial structure loads and load combinations are specified in Section 12.5. Track-Structure Interaction requirements and those specific load combinations are specified in Section 12.6. Seismic requirements are specified in the *Seismic* chapter.

12.8.3 Foundations

12.8.3.1 Shallow Foundation Design

Shallow foundations such as spread footings shall be designed in accordance with AASHTO LRFD with Caltrans Amendments. Soil and rock engineering properties shall be based on the results of field investigations as presented in the Geotechnical reports described in the *Geotechnical* chapter. Use of presumptive values shall not be allowed.

12.8.3.2 Deep Foundation Design

Design of deep foundations shall be based on project-specific information developed for the location(s) and foundation type planned. Soil and rock engineering properties shall be based on the results of field investigations as presented in the Geotechnical reports described in the *Geotechnical* chapter. Use of presumptive values shall not be allowed. Bottom clean out of drilled shafts constructed using the wet method shall be verified.

Where permanent steel casing is used for structural capacity, it shall have a minimum wall thickness of 3/4 inch and be provided with internal shear lugs if composite action is to be relied upon. Additionally, the design basis of the steel section shall be reduced to account for corrosion over the life of the structure based on actual soil and ground water conditions. A site specific corrosion study shall be performed to determine the deduction of the wall thickness due to the corrosive characteristics. A minimum of 1/8 inch reduced wall thickness shall be applied. Steel casing shall not be considered for structural support in extremely aggressive environments.

Construction tolerance for drilled shafts shall be in accordance with AASHTO LRFD with Caltrans Amendments. For trackway shafts greater than 5 feet in diameter, the drilled shafts shall be designed assuming they are offset at the top of the shaft a minimum of 6 inches. Refer to the Standard Specification on Drilled Concrete Piers and Shafts.

Geotechnical Design of mini-piles shall be in accordance with AASHTO LRFD with Caltrans Amendments, Section 10.9 Micropiles and FHWA-SA-97-070 (Micropile Design and Construction Guidelines, June 2000).

The upper 5 feet as measured from lowest adjacent grade shall be discounted in any axial and lateral load analyses except where it can be shown that measures are provided to prevent future excavations around the pile within three diameters from the shaft or pile group exterior surface. For the analysis to obtain the demand forces the upper 5 feet shall be considered.

12.8.4 Steel Structures

Steel through trusses and through girders may be used for longer spans requiring minimal structure depth and other steel built up sections, beams and girders may be used over railroads or highways. For through and semi-through type bridges the requirements of Section 12.5.2.13 shall be met for structural elements within 16 feet of the track centreline. Loadings shall be considered as derailment loads applied in the Extreme 1 Load Combination in Table 12-4.

12.8.4.1 Continuous Steel Structures

For continuous girders and other statically indeterminate structures, the moments, shears, and thrusts produced by external loads shall be determined by elastic analysis. The effects of creep, shrinkage, axial deformation, restraint of attached structural elements, and foundation settlements shall be considered in the design.

12.8.4.2 Fracture Critical Members

Fracture critical members shall be designed in accordance with AASHTO LFRD with Caltrans Amendments. A load factor of 1.50 shall apply to live load of the Fatigue load combination described in Table 12-4. Welding in tension zones in fracture critical members is not permitted.

12.8.4.3 High Performance Coating

Steel Bridges shall have a high performance coating system such as polysiloxane, polyaspartic modified urethane, or fluoropolymer which may be applied in the field. Primer shall be inorganic or organic zinc as recommended by the manufacturer of finish coats. Coatings including primers shall comply, at a minimum with South Coast Air Quality Management District (SCAQMD) Rule 113.

The Contractor shall provide services of an independent coating inspector. Independent coating inspector shall be certified under NACE International’s Certified Inspector Program as a Certified Coating Inspector.

12.8.4.4 Orthotropic Steel Decks

Steel orthotropic plate decks shall not be used for the HST mainline structures.

12.8.4.5 Bearing Replacement

Reinforced jacking points shall be identified clearly on As-Built drawings.

12.8.4.6 Inspection and Maintenance

Construction details of steel bridges shall facilitate maintenance and inspection so that inspection and maintenance can be performed during non-revenue service. Structures over railroads or highways shall provide for the inspection and maintenance during limited access to the below deck elements. Steel box girders and box beams shall have access hatches to allow maintenance and inspection of the member.

12.8.5 Concrete Structures

Aerial structures, bridges and grade separation superstructures may be constructed using cast-in-place concrete, precast girders either single span, span by span or segmental, as well as cast-in-place, segmental balanced cantilever or incrementally launched methods. Concrete through girders shall meet the same requirements as steel through girders.

The CEP-FIP Model Code for Concrete Structures shall be used for determining time dependent effects due to creep, shrinkage and prestressing steel relaxation.

12.8.5.1 Longitudinal Tension Stresses in Prestressed Members

AASHTO LRFD with Caltrans Amendments shall be used for allowable longitudinal tension stresses. Tension stresses are not allowed in pre-compressed tensile zones after all losses have occurred.

12.8.5.2 Additional Requirements for Segmental Trackway Construction

Shear and torsion design to conform to AASHTO LRFD, Article 5.8.6, in addition to AASHTO LRFD with Caltrans Amendments.

Principal tensile stresses in webs to conform to AASHTO LRFD with Caltrans Amendments, Article 5.8.5.

Precast segmental concrete construction with dry segment joints is not permitted. Joints in precast segmental bridges and viaducts shall be either cast-in-place closures or match cast epoxied joints.

Hollow columns shall have a solid section minimum 5 feet above finished grade or 12 feet above high water level. Vertical post-tensioning is not allowed in the solid sections. An access opening shall be provided near the top of the column. See Section 12.8.10 for sizes. Access openings shall be located outside of potential plastic hinge zones. Internal platforms and ladders shall be provided.

Two inch diameter vent holes are required through the bottom flange of box girders near each end of each span.

12.8.5.3 Crack Control

The design of prestressed concrete or reinforced concrete aerial structures shall consider the effect of temporary loads imposed by sequence of construction stages, forming, falsework, and construction equipment, as well as the stresses created by lifting or placing pre-cast members, stress concentration (non-uniform bearing at the ends of pre-cast beams), end block design and detailing, methods of erection, shrinkage, and curing. Ensure that the structural design and detailing of pre-stressed or reinforced concrete members is adequate and meets durability requirements and that specifications are prepared which are compatible with the design so that crack widths are no greater than allowed by AASHTO LRFD with Caltrans Amendments Class 2 exposure condition in construction stages or service. If the concrete member is continuously

submerged in water or is a zone of intermittent wetting and drying the exposure factor used in AASHTO LRFD with Caltrans Amendments Article 5.7.3.4 shall be 0.25 or less.

12.8.5.4 Maintenance and Inspection of Concrete Structures

Inspection and maintenance hatches shall be provided into each closed girder. These hatches may be through the girder soffits or in combination with openings between adjacent girder diaphragms.

The minimum headroom inside of typical box girders shall be 6 feet. For two- or three-span short bridges with spans less than 90 feet, the minimum headroom inside of box girders shall be 4 feet.

Minimum clearance from girder ends to bearings and from abutment backwalls to bearings shall be 2.5 feet to allow for access.

In-span hinges and associated expansion joints are not allowed.

12.8.5.5 Continuous Concrete Structures

For continuous girders and other statically indeterminate structures, the moments, shears, and thrusts produced by external loads and prestressing shall be determined by elastic analysis. The effects of creep, shrinkage, axial deformation, restraint of attached structural elements, and foundation settlements shall be considered in the design.

12.8.6 General Aerial Structure and Bridge Design Features

12.8.6.1 Bridge Skew

The preferred angle of crossing and bridge structure relative to the centerline of track is 90-degrees. In cases where a 90-degree crossing cannot be constructed, the skew of the bridge shall be limited so that for each track the deck end is between successive rail fasteners and the applicable provisions of Section 12.6 Track-Structure Interaction are met. The maximum skew of a bridge from 90-degrees shall not exceed 30-degrees.

12.8.6.2 Embankment Length Between Abutments

The length of embankment between abutments shall not be less than 500 feet. The length of embankment between an abutment and a culvert shall not be less than 100 feet. If closer spacing is required, then the embankment shall be specially treated such that a constant gradient of stiffness shall be provided between the two adjacent bridge deck stiffnesses. Refer to the *Geotechnical* chapter for specific requirements for embankment fills and abutment backfill.

12.8.6.3 Containment Barriers

Containment barriers as described in Section 12.5.2.13-B are required on all bridges and aerial structures.

12.8.6.4 Intrusion Protection

Aerial structures shall be protected from errant highway vehicles as well as from derailed trains as described in the *Rolling Stock and Vehicle Intrusion Protection* chapter and as required in the following:

A. Highway Traffic Intrusion

HST substructures, as required by the *Rolling Stock and Vehicle Intrusion Protection* chapter, shall be protected by an appropriate barrier as specified AASHTO LRFD with Caltrans Amendments Article 3.6.5.1 or designed for the force presented in AASHTO LRFD with Caltrans Amendments, Article 3.6.5.2.

B. Railroad Intrusion

HST substructures located adjacent to conventional railroad shall be protected as specified in the *Rolling Stock and Vehicle Intrusion Protection* chapter. The design shall follow the requirements of AASHTO LRFD with Caltrans Amendments, Article 2.3.3.4. If an independent intrusion barrier is not provided, the substructure shall be designed to resist forces presented in Section 12.5.2.14.

12.8.6.5 Uplift

There shall be no net uplift at any support for any combination of loadings.

12.8.6.6 Friction

Friction shall be considered in the design where applicable.

12.8.6.7 Sound Barriers

Sound barriers, both presence and absence, shall be considered in the evaluation of stress, vibration, and deflection limits.

12.8.6.8 Drainage

Drainage of water from aerial structures, bridges and grade separations shall be accomplished by sloping the deck towards the center of the deck, and sloping the girders towards a pier support or abutment. Water shall be collected and conveyed to a drainage pipe cast into the concrete substructure. The pipe shall pass through the pier columns and abutment walls to exit through the foundations. Column reinforcing in potential plastic hinge zones shall not be interrupted for drain pipes. Refer to the *Drainage* chapter for other requirements.

12.8.6.9 Expansion Joints

Expansion Joints shall be provided between girder ends and between girder end and abutment walls to allow superstructure movements and prevent water and other material from falling from the superstructure. Expansion joints are not required to resist highway or rail traffic loads, but shall be protected from ballast if ballast is used. Expansion joints may be part of a bridge drainage system.

The design life of expansion joints is given in the *General* chapter. Expansion joints shall be detailed to allow replacement during the five hour non revenue service maintenance work window. Refer to Section 12.6 for length of thermal units.

Rail expansion joints are described in the *Trackwork* chapter with uses and limitations.

A. <u>Structural Expansion Joints (SEJ)</u>

The detailed design of structural expansion joints shall:

1. Provide free movement space in the bridge longitudinal direction for:
   - creep, shrinkage, temperature variation, braking and acceleration.
   - creep, shrinkage, temperature variation, single track braking and OBE.

   Expansion joints and connections to the structure shall be capable of resisting loads transmitted through the ballast under these loading conditions.
2. Provide enough space between two adjacent structures to prevent unbuffered impact between them during a MCE earthquake.
3. For ballasted track, if buried type expansion joints are used, no part of the structure expansion joints shall protrude above top surface of the protection layer for waterproofing membrane.

The Contractor shall adjust the joint gap during installation to accommodate the effects of prestressing including shrinkage and creep, and the difference between the ambient temperature and the design temperature.

An assessment of the longitudinal actions shall be made and the movement checked in accordance with the requirements of Section 12.6.

The installation of turnouts and SEJ shall be based on requirements in Section 12.8.6.9-B.

B. <u>Structure Expansion Joints in Special Trackwork</u>

Structural joints may be placed within turnout and crossover units as needed to minimize relative movement between structures and track. Structural joints shall not be located within areas of special track supporting plates nor within the vicinity of the movable portions of switches and frogs. Longitudinal joints in structures shall not be located under crossover tracks. Structural joints under special trackwork units shall be perpendicular or close to perpendicular to the orientation of the track. Potential movement of the structure relative to the track shall be oriented with the alignment of the track.

Permissible and prohibited locations for joints are illustrated in Figures 12-34 and 12-35 and the limiting location dimensions given in the Tables 12-25 and 12-26.

Figure 12-34: Joint Location Limitations at Low-Speed Turnouts

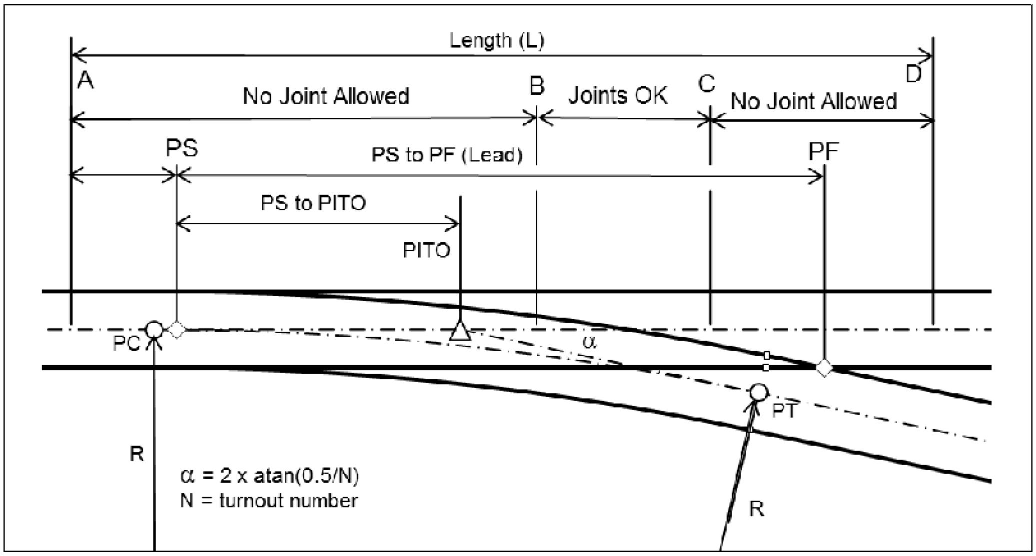

Table 12-25: Joint Location Limitations at Low-Speed Turnouts

Turnout Properties					Location of points defining limits of joints (feet)				Length of No Joint / Allowed Joint Zones (feet)		
Internal Radius (feet)	PC to PS (feet)	N	Turnout angle α	PS to PI (feet)	PS to A	PS to B	PS to C	PS to D	No Jt. A to B	Jt. OK B to C	No Jt. C to D
620.0	1.69	9	6d21m35s	32.75	20.0	40.6	62.2	86.8	60.6	21.5	24.6
950.0	1.93	11	5d12m18s	41.25	20.0	50.3	77.0	107.2	70.3	26.7	30.2
1,750.0	2.58	15	3d49m06s	55.75	25.0	68.3	104.5	145.8	93.3	36.2	41.3
3,275.0	3.25	20	2d51m51s	78.00	25.0	93.1	142.5	198.0	118.1	49.4	55.5
4,650.0	3.87	24	2d23m13s	93.00	25.0	111.3	170.4	237.0	136.3	59.1	66.6

Figure 12-35: Joint Location Limitations at High-Speed Turnouts

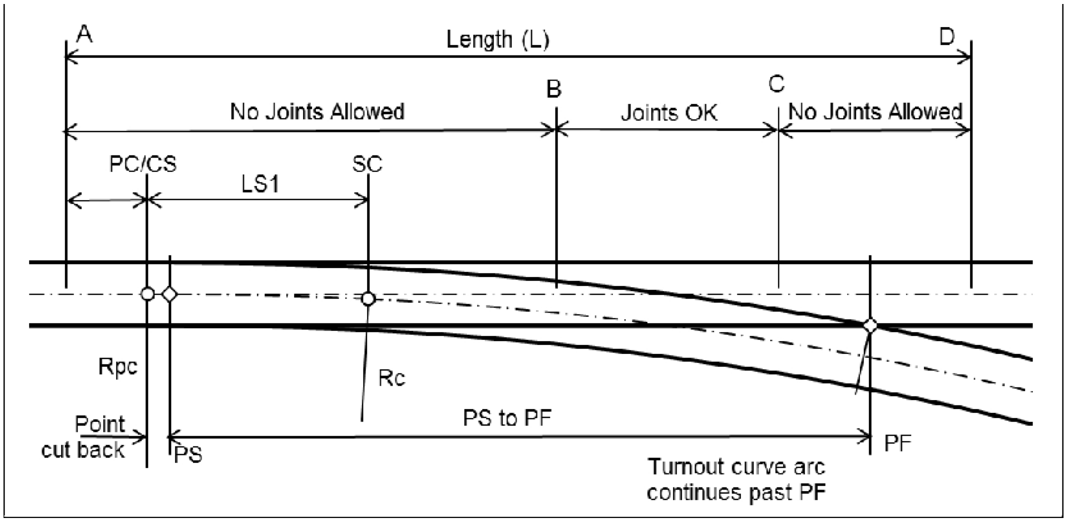

Table 12-26: Joint Location Limitations at High-Speed Turnouts

Turnout Properties					Location of points defining limits of joints (feet)				Length of No Joint / Allowed Joint Zones (feet)		
Design Speed (mph)	Entry Radius Rpc (feet)	entry spiral length (feet)	body radius Rc (feet)	Switch point cutback (feet)	PC to A	PC to B	PC to C	PC to D	No Jt. A to B	Jt. OK B to C	No Jt. C to D
60	10,000	90.00	5,000	6.00	24.0	134.2	207.3	270.7	158.2	73.0	63.4
80	18,000	120.00	9,000	8.00	22.0	180.0	278.0	363.1	202.0	98.0	85.1
110	34,000	160.00	17,000	11.00	29.0	246.6	381.1	498.0	275.6	134.5	117.0
150	80,000	220.00	32,000	16.00	24.0	348.9	533.6	694.2	372.9	184.8	160.6

For the 150 mph turnout a design variance will be required for structural arrangement.

12.8.6.10 Longitudinal joints in Special Trackwork

In zones of special trackwork, where tracks will cross between parallel superstructure elements such as girders, those superstructure elements shall be connected into a continuous deck that can support the tracks as well as a derailed train with loads described in Section 12.5.2.13. The deck shall be cast in place or made continuous with a longitudinal closure strip between decks. The transverse strengthening shall also include rigid diaphragms, post-tensioning, welded steel plates or other such strengthening elements. Railroad box sections post-tensioned together shall be considered to have a continuous deck. This continuity shall extend from the Point A indicated in Figures 12-34 and 12-35 before the point of switch to the equivalent Point A at the opposite end of the turnout beyond the final point of tangent in the special trackwork. This continuity is independent of the structural expansions describes in Section 12.8.6.9.

12.8.6.11 Bearings

AASHTO LRFD with Caltrans Amendments shall be used for design of bearings. Elastomeric bearings, disk bearings, spherical bearings and seismic isolation bearings are allowed. If seismic isolation bearings are used, the design shall follow the requirements of the *Seismic* chapter. Longitudinal and lateral restraints shall be placed to minimize eccentric deformations.

The design life of bearings shall be as presented in the *General* chapter. Since bearings will be replaced during the life of the structures an inspection and replacement plan for bearings shall be provided. Inspection and replacement will be allowed only during the non-revenue service hours of the HST such that train operations are not affected by the inspection or replacement.

12.8.6.12 Rail Stresses and Deformations of Aerial Structures

High-speed trains are very sensitive to deformations of the tracks. See Section 12.6 – Track-Structure Interaction for additional requirements related to track structure interaction, resonance and dynamic performance.

12.8.6.13 Resonance of High Speed Trains on Repetitious Spans

Amplification of vibrations has been observed on high-speed trains traveling on long viaducts where the same span is repeated many times. It affects ride quality. In order to limit this response long viaducts shall have span length modified every 20 spans or 2000 feet. The modification shall include at least two spans reduced in length by 20 percent from the typical span between column centers. Following spans shall resume from the new column location rather than from the original column layout.

12.8.6.14 Camber and Deflections for Aerial Trackway Structures

Structures shall be built with camber equal to the sum of deflections under dead load of steel structural components and permanent attachments (DC), dead load of non-structural and non-permanent attachments (DW), and one track of modified Cooper E-50 loading plus impact (LLRM+I)[1].

The total long-term predicted camber growth, less deflection due to full dead load, shall be less than 1/5000 of the span length for prestressed concrete aerial structures measured 10,000 days after casting concrete.

To ensure rider comfort, the deflection of longitudinal girders under normal live load plus dynamic load allowance shall be as described in Section 12.6 – Track-Structure Interaction.

12.8.6.15 Structure Deformation and Settlement

The control of deformations through proper structural design is of paramount importance in obtaining acceptable ride quality for the rail vehicles and passengers. Consider structure deformations, including foundation settlement, for their effects on structural behavior but also and on trackwork. As a minimum, trackway piers and abutments settlement as measured at the top of concrete of the finished trackway girder deck shall be limited as prescribed in the *Geotechnical* chapter.

12.8.6.16 Superelevation on Aerial Structures

Superelevation of tracks through curved track shall be accomplished through the trackwork. Girder decks shall maintain a level attitude transverse to the track with deck slope allowed only for drainage.

12.8.6.17 Walkways, Parapets, and Sound Walls

Loads on walkways shall be as described in Section 12.7.1.4. Walkways shall be precast or cast-in-place concrete. The walkway shall be on the cover of the cable trough. The cable trough cover shall be a non-skid material and the cover shall be anchored using positive connections to resist loads described Section 12.5. Walkways shall follow requirements on the Standard and Directive Drawings.

Parapets shall be provided along edges of aerial structures, bridges, and HST grade separation structures. Parapets shall be designed for wind loads, slipstream effects, and other loadings in Section 12.5. Parapets shall be designed to accommodate installation of sound walls.

Parapets and safety railings shall be designed to withstand the forces in Section 12.7.1.6. In locations where conduit risers are required along the alignment, parapets may be required to support conduits.

Temporary railings may be necessary to provide safety after girders are placed and before parapets are placed. Temporary railings shall meet the same requirements as safety railings. Temporary railings may be needed between construction contracts.

The height of sound walls shall be determined based on results from the noise attenuation study. The sound wall and its connection to the structure shall be capable of resisting the slipstream effects from passing trains and the wind load as described in Section 12.5. No gap shall be permitted between the bottom of sound wall and the structure deck, nor any vertical gaps between the sound wall panels.

12.8.7 Complex and Non-Standard Aerial Structures

For the definitions of standard, complex and non-standard structures see *Seismic* chapter. Some structures and structural systems involve unique design, construction, and performance problems not covered by these criteria. Some specific requirements follow:

- Straddle and outrigger bents have cap beams that extend beyond the edges of superstructure toward columns located outside of the superstructure.
  - The load path necessary to accommodate longitudinal actions of the superstructure shall be defined in a report and submitted with the Type Selection Report to the Authority, see Section 12.8.1.
  - Torsion cracking in the primary load path is not permitted in concrete beam members. Compatibility torsion is allowed.

– Torsional rotation of concrete columns is not permitted under seismic actions when high bending and shear stresses occur.

12.8.8 Emergency Access

Where access stairs are provided, the emergency stairs shall be at the edge of deck. A safety gate opening away from the track shall be provided at each access opening. The safety gate shall be designed to resist wind and slipstream forces from Section 12.5 as well as live loads in Section 12.7.

12.8.9 OCS Pole and Traction Power Facility Gantry Supports

Girder decks shall be designed to accommodate and support OCS poles and Traction Power Facility Gantry. Loads are described in Section 12.5. Conduit or sleeves for future conduit shall be provided from external power sources to the OCS poles and Traction Power Facility Gantry.

12.8.10 Maintenance of HST Aerial Structures, Bridges, and Grade Separations

Because of the large number of structures along the line, special care shall be taken in the design to reduce maintenance requirements. The following requirements shall apply:

- Reinforced or prestressed concrete structures are preferred over steel structures. The Designer shall justify in writing the use of steel structures, demonstrating the benefits of any steel structure.
- Bearings shall be easily accessible for inspection. They shall be adjustable and replaceable at any time during the life of the structure without disrupting train normal operations. Bearing replacement shall be completed within non-revenue hours. During this period train speed may be limited at location where bearing is being replaced. The design documents shall provide a description of the procedures for bearing replacement, including the location of the jacks with safety nuts and a calculation of forces.
- Access arrangements for maintaining exterior surfaces or equipment attached thereto shall be provided from the ground or from movable gantries. At intervals not greater than 300 feet and at one location in the case of a shorter isolated structure, 2.5 feet x 5 feet access openings with steel grating for inspection and maintenance shall be provided in the bottom slabs close to the expansion joint piers. For tall and long structure access openings may be at both ends near abutments.
- If a pier is not accessible from the ground beneath, such as river crossing bridge, a 3 feet x 3 feet access opening with steel grating shall be provided in the bottom slab of decks so that the pier top can be reached from the inside of the box girder. Beside this opening, a work platform shall be provided at the pier top for the maintenance of bearings.

- In the design of bridges, the vertical load of maintenance the gantry on the deck overhang shall be taken into consideration. The maintenance gantry shall be represented by a line load of 30 kips over a length of 13 feet applied to the edge of the cantilever deck.
- A lifting hook capable of lifting 7500 pounds shall be embedded in the underside of the superstructure top slab above each access opening. Access openings shall be equipped with lockable galvanized steel hatches.

12.9 Requirements for Bridges not Supporting HST

Bridges not supporting HST are classified as either Primary Type 2 or Secondary in the *Seismic* chapter. Secondary Bridges shall be designed to either the requirements of AASHTO LRFD with Caltrans Amendments for pedestrian and highway bridges, or AREMA Manual for Railway Engineering for railroad bridges. Primary Type 2 structures shall meet the requirements described below.

12.9.1 Load Requirements for New Primary Type 2 Pedestrian Bridges

New Primary Type 2 pedestrian bridges shall be designed according to AASHTO LRFD Guide Specifications for the Design of Pedestrian Bridges, with seismic design according to the *Seismic* chapter.

New Primary Type 2 pedestrian bridges shall not have expansion joints or other features requiring special maintenance in the HST right of way. Access shall be reserved for inspection and routine maintenance without impacting HST operations or endangering bridge maintenance inspectors.

Local County, City, or third party bridges shall follow requirements of the local jurisdiction.

12.9.2 Load Requirements for New Secondary Pedestrian Bridges

Bridges or structures that support pedestrian loadings not spanning and classified as Secondary structures shall be designed according to AASHTO LRFD Guide Specifications for the Design of Pedestrian Bridges and with the seismic provisions of CSDC. OBE is not required unless seismic performance has the potential to directly impact HST service.

12.9.2.1 Existing Pedestrian Bridges

Existing Primary Type 2 pedestrian bridges shall be evaluated to determine a Bridge Health Index. HST horizontal and vertical clearances shall meet the clearance requirements specified in the *Trackway Clearances* chapter. Existing Primary Type 2 pedestrian bridges that are load restricted or a Bridge Health Index (Sufficiency Rating) less than 80 shall be replaced.

For existing Primary Type 2 pedestrian bridges that do not meet seismic performance requirements according to the *Seismic* chapter, retrofit shall be required and a Seismic Design and Analysis Plan submitted as required in the *Seismic* chapter.

12.9.2.2 Live Load or Pedestrian Bridges

Areas where cash carts are used shall be designed to accommodate a point live load of 350 pounds per wheel.

Areas where station equipment will be transported shall be designed for a load of 2000 pounds spread over a square with sides of two feet.

12.9.2.3 Frequency and Vibration Limits for Pedestrian Bridges

Pedestrian bridges or structures shall meet the requirements for pedestrian comfort specified in Section 12.7.1.13 – Frequency and Vibration Limits.

12.9.3 Requirements for Highway Bridges

Bridges or structures that support highway loadings not spanning over HST structures or alignments, shall be designed according to AASHTO LRFD with Caltrans Amendments and with the seismic provisions of CSDC and follow the Office of Specially Projects Information and Procedures Guide for Planning Studies and Type Selection to achieve approval from the Department of Transportation. County, city and other bridges shall follow requirements of these jurisdictions.

12.9.3.1 New Highway Bridges

New highway bridges that are classified as Primary Type 2 structures shall be designed according to AASHTO LRFD with Caltrans Amendments and with seismic design following the requirements of the *Seismic* chapter and meeting the durability requirements herein in addition to requirements of the bridge owner.

New Primary Type 2 highway bridges shall not have expansion joints or other features within the HST right of way requiring maintenance. Access shall be reserved for safe inspection and normal maintenance of the highway bridge over the HST without impacting train operations or endangering bridge maintenance inspectors.

Bridges supporting the California State Highway System (SHS) shall follow the procedures in the State of California Department of Transportation procedures described in the Office of Specially Projects Information and Procedures Guide for Planning Studies and Type Selection to achieve approval from the Department of Transportation. County, city and other bridges shall follow requirements of these jurisdictions in addition to the requirements herein.

12.9.3.2 Existing Highway Bridges

In situations where HST must pass under an existing highway bridge and are thus classified as Primary Type 2 bridges, the highway bridge shall be evaluated for its continued service. Each bridge shall:

- be accepted as-is
- or, repaired or retrofitted to meet these criteria

- or replaced with a new bridge

The determination of the appropriate selection starts with the current Caltrans Bridge Health Index to be provided by Caltrans. Structures that are load restricted or a Bridge Health Index (Sufficiency Rating) equivalent to or less than 80 shall need replacement. Bridge Health Index less than 90 shall require repair to bring the Index to above 98 prior to start of train service.

The seismic performance requirements described in the *Seismic* chapter for Primary Type 2 bridges shall be satisfied. For existing SHS structures that do not meet HST structural or seismic performance requirements as described in the *Seismic* chapter, an As-Built assessment shall be performed based upon best available information and in accordance with HST for Primary Type 2 bridges and described in the Seismic Design and Analysis Plan required in the *Seismic* chapter. For structures not meeting these requirements a seismic retrofit shall be required. The proposed seismic retrofit shall be prepared according to the Seismic Design and Analysis Plan and reviewed by Caltrans and the Authority for agreement on a complete seismic retrofit strategy for both MCE and OBE risk levels and the corresponding performance described in the *Seismic* chapter.

The horizontal and vertical clearances shall be evaluated by the Contractor to meet the requirements in the *Trackway Clearances* chapter. Structures that cannot meet clearance requirements or cannot obtain variance approval shall require modification or replacement.

Evaluation will consider if the bridge is structurally deficient or functionally obsolete. Continued operation of the “as is” facility, seismic retrofit/rehabilitation, or replacement will be made by the Authority in conjunction with the owner and the Contractor.

Mitigation measures shall be considered for all existing structures. Such mitigations may include modifying HST alignments to satisfy clearance envelopes; constructing track protection shields to keep structural debris from affecting train service; constructing catcher frames to support displaced existing girders to minimize impacts to HST due to post-seismic event recovery; and/or replacement of the existing structure.

12.9.4 Requirements for New Railway Bridges

New Primary Type 2 railway bridges shall be designed according to AREMA and the requirements of the railroad owner and operator with seismic design according to the *Seismic* chapter.

New Primary Type 2 railway bridges shall not have expansion joints or other features requiring special maintenance in the HST right of way. Access shall be reserved for inspection and routine maintenance without impacting HST operations or endangering bridge maintenance inspectors.

Existing freight rail bridges spanning over the HST right of way shall be inspected, assessed and evaluated to prepare a recommendation for either acceptance “as is”, seismic retrofit/repair, or

replacement by the Contractor. The seismic requirements for a primary structure as defined in the *Seismic* chapter shall be followed.

12.9.5 Requirements for Existing Railway Bridges

Existing Primary Type 2 railway bridges shall be evaluated to determine a Bridge Health Index. A Bridge Health Index of less than 80 shall require a bridge replacement. HST horizontal and vertical clearances shall meet the clearance requirements specified in the *Trackway Clearances* chapter.

For existing Primary Type 2 railway bridges that do not meet seismic performance requirements according to the *Seismic* chapter, retrofit shall be required and a Seismic Design and Analysis Plan submitted as required in the *Seismic* chapter.

12.9.6 Intrusion Protection

If a pedestrian, highway, or railway bridge column is located adjacent to the HST alignment, then intrusion protection shall be provided. Barriers shall be designed to meet the requirements in Sections 12.5.2.14 and 12.7.1.9. Intrusion protection requirements are defined in the *Rolling Stock and Vehicle Intrusion Protection* chapter.

12.10 Earth Retaining Structures

Earth retaining structures shall be designed to lateral earth pressures in accordance with the *Geotechnical* chapter. Top of retaining walls, including fill, cut, and trench walls, shall be at least 1 foot above finish grade and provided with fall protection barriers as per Cal/OSHA. Wall heights may be higher as required for flood elevation and intrusion protection requirements. Walls with Access Deterring (AD) or Access Restricting (AR) fencing, per the *Civil* chapter, can serve as fall protection provided that the fencing meets Cal/OSHA requirements.

Temporary support excavation systems shall not be part of the permanent earth retaining structures.

12.10.1 Earth Pressure Acting on Retaining Structures

For earth pressure acting on retaining structures, see the *Geotechnical* chapter.

12.10.2 Retaining Walls

Retaining walls shall be designed in accordance with requirements of the *Geotechnical* chapter. Retaining walls shall be constructed with expansion joints in walls a maximum of 72 feet apart. Construction joints shall be a maximum of 24 feet apart.

12.10.3 MSE Walls

Mechanically stabilized earth walls shall be designed in accordance with requirements of the Geotechnical Reports in the *Geotechnical* chapter. If not specified in any reports, the MSE wall design shall follow the requirements specified in AASHTO LRFD section 11.10 with Caltrans amendments.

12.10.4 Trenches

Trenches are below grade structures with a retaining structure on both sides. Often the retaining structures are joined by a common reinforced concrete foundation. Waterproofing of the bottom of slab, and outside of walls is required if the top of concrete foundation slab is below the water table, see Section 12.11.3. For hydrostatic pressure (buoyancy), refer to Section 12.11.2.7.

Trench walls are considered to be rigid, so the minimum earth pressure coefficient is the At-rest earth pressure. Wall heights shall be based on flood and intrusion protection. The wall height shall not be less than 1 foot above finished grade.

12.10.5 Trench Intrusion Protection

HST trench structures shall be protected from errant highway vehicles and derailed trains as described in the *Rolling Stock and Vehicle Intrusion Protection* chapter and as required in the following.

12.10.5.1 Highway Traffic Intrusion

HST trench structures shall be protected by a continuous Caltrans type concrete barrier as specified in the *Rolling Stock and Vehicle Intrusion Protection* chapter. The trench wall shall be designed for the force presented in AASHTO LRFD with Caltrans Amendments Article 3.6.5.

12.10.5.2 Railroad Intrusion

HST trench structures located adjacent to conventional railroad shall be protected as specified in the *Rolling Stock and Vehicle Intrusion Protection* chapter. Where an independent intrusion protection cannot be constructed due to limited space, the trench wall, next to the conventional railroad, shall be constructed as described in *Rolling Stock and Vehicle Intrusion Protection* chapter and the wall shall be designed to resist forces presented in Section 12.5.2.14.

12.10.6 Struts

Struts may be used to support earth pressures in trenches. The minimum height of struts shall be 27 feet clear from TOR.

12.10.7 Trench Drainage

Trenches shall be drained to the low point of sag curves. Sump pumps and an interconnected sump and pump room shall house the pumps. Earth pressures on the sump structure shall be as

required in the Geotechnical reports described in the *Geotechnical* chapter. Sump structures shall be made water proof from ground water. Refer to the *Drainage* chapter.

12.10.8 Trench Emergency Exits

Emergency exits are required from trenches at a minimum spacing of 2,500 feet. There shall be at least one emergency exit in each trench. The exit shall include an enclosed stairway from the walkway to ground surface and a secured head house at the surface.

12.11 Cut-and-Cover Structures

The criteria set forth in this section govern the static load design of cut-and-cover underground structures with the exception of pile foundations. Cut-and-cover structures include line structures, crosspassages, sump pump structures, underground stations, vaults, ventilation structures, and other structures of similar nature. Portal and ventilation requirements and minimum cross sectional tunnel areas shall be as required in the *Tunnels* chapter.

The design of structures within the scope of this section shall be in accordance with the provisions set forth in these criteria and shall also meet the requirements of the AASHTO LRFD with Caltrans Amendment, CBC, ACI, AISC and AWS, except where such requirements are in conflict with these criteria.

12.11.1 Structural System

Structural system for cut-and-cover line structures shall be single and/or multi-cell reinforced concrete box structures, with walls and slabs acting one-way in the transverse direction to form a continuous frame. Temporary excavation support systems shall not be used as whole or part of the permanent walls. Expansion or contraction joints are required at locations of major change in structural sections such as from line structure to station. Construction joints shall have continuous reinforcing steel, non-metallic waterstops and sealants.

12.11.2 Loads and Forces

Components of underground structures shall be proportioned to withstand the applicable loads and forces described in Section 12.5.

Cut-and-cover structures shall, at minimum, be designed for the forces described herein.

12.11.2.1 Zone of Influence

Zone of Influence is defined as the area above a positive Line of Influence which is a line from the critical point of substructure at a slope of 2 horizontal to positive 1 vertical (line sloping towards ground level) or the area below a negative Line of Influence which is a line from the critical point of substructure at a slope of 2 horizontal to negative 1 vertical (line sloping away from ground level).

12.11.2.2 Future Traffic Loads

An area surcharge applied at the ground surface both over and adjacent to underground structures is to simulate possible roadway and sidewalk live loads. This surcharge is intended to simulate conditions during future construction activities adjacent to the underground structures. Such construction may result in permanent loads or in temporary loads from construction equipment from the stockpiling of construction materials, or from the deposition of excavated earth. It is possible that loads such as those from hauling trucks, may be applied inadvertently to the underground structures due to their innate inconspicuousness.

12.11.2.3 Alternative Traffic Loading

For the underground structures beneath or adjacent to operating railroads, both the vertical and lateral surcharge shall be based on Cooper's E-80, defined by AREMA MRE, railroad surcharge loadings. Refer to the standards of the subject railway.

For the underground structures adjacent to existing highway bridge overcrossings, both the vertical and lateral surcharge shall be based on the operating loads from the contractor's equipment with a minimum surcharge loadings equivalent to a 100-ton crawler crane.

For underground structures beneath highways, city streets or planned roadways, the applied vehicular live load shall be based on the HL-93 loading according to the AASHTO LRFD with Caltrans Amendments. For underground structures which are not anticipated to be beneath railroads, overcrossings, highways, streets, or roadways, the applied live load shall be based on no less than HL-93 loading according to the AASHTO LRFD with Caltrans Amendments. The distribution of this live load shall be in accordance with the following:

- Fill height less than two feet - live load shall be applied as concentrated loads directly to the top of the slab.
- Fill height greater than two feet - concentrated live loads shall be distributed over a square area, the sides of which shall equal 1.75 times the depth of the fill.
- When distribution areas overlap, the total load shall be uniformly distributed over an area defined by the outside limits of the individual areas.

For design of the top slab of underground structures supporting the alternative traffic loading, impact loading (I) shall conform to AASHTO LRFD with Caltrans Amendments, Article 3.6.2.2. The fill height shall be measured from the top of ground or pavement to the top of the underground structure.

12.11.2.4 Existing Structures

Existing structures that are to remain in place above underground structures shall either be underpinned in such a manner as to avoid increased load on the underground section, or the section shall be designed to support the structure directly. Third party structures shall be supported directly on HST structures only with specific approval in writing by the Authority.

Underground structures shall be designed for additional loading from existing adjacent buildings or structures unless they are permanently underpinned or have foundations to below the zone of influence. A building shall be considered to be adjacent to an underground structure when the horizontal distance from the building line to the nearest face of the underground structure is less than 2 times the depth of the underground structure invert below the building foundation.

Each existing structure shall be considered individually. In the absence of specific data for a given height of building and type of occupancy, applicable foundation loads shall be computed according to the CBC and the additional uniform lateral pressure on that portion of the underground structure sidewall below the elevation of the building foundation shall be distributed as shown on the preliminary engineering drawings. If distribution is not indicated on the preliminary engineering drawings, designer shall determine distribution.

12.11.2.5 Requirements for Future Structures

Some cut-and-cover structures must be designed to accommodate future structures in close proximity. Guidelines are provided below for a general case. Additional requirements may be required on a case-by-case basis.

A. Clearance

Structures over or adjacent to HST underground structures shall be designed and constructed so as not to impose any temporary or permanent adverse effects on underground structures. The minimum clearance between any part of the adjacent structures to exterior face of substructures shall be 7 feet–6 inches. Minimum cover of 8 feet shall be maintained wherever possible.

B. Surcharge

In general, cut-and-cover structures are designed with an area surcharge applied at the ground surface both over and adjacent to the structures. The area surcharge is considered static uniform load with the following value:

D (feet)	Additional Average Vertical Loading (psf)
D>20	0
5<D<20	800-40D
D<5	600

Where D is the vertical distance from the top of the underground structure roof to the ground surface.

C. Shoring

Shoring is required for excavations in the Zone of Influence. Zone of Influence is defined in Section 12.11.2.1.

D. <u>At-Rest Soil Condition</u>

See the *Geotechnical* chapter for soil loads and pressures needed for design.

E. <u>Soil Redistribution</u>

See the *Geotechnical* chapter for soil redistribution caused by temporary shoring or permanent foundation system.

F. <u>Dewatering</u>

Dewatering shall be monitored for changes in groundwater level. Recharging will be required if existing groundwater level is expected to drop more than 2 feet.

G. <u>Piles Predrilled</u>

Piles shall be predrilled to a minimum of 10 feet below the Line of Influence. Piles shall be driven in a sequence away from HST structures. No pile will be allowed between steel-lined tunnels.

H. <u>Vibration During Pile Driving</u>

Underground structures shall be monitored for vibration during pile driving operations for piles within 100 feet of the structures. Tunnels shall also be monitored for movement and deformation. Requirements for monitoring will be provided upon request.

I. <u>Future Excavation Adjacent to Cut-and-Cover</u>

The design of cut-and-cover structures shall consider an unbalanced lateral load condition due to possible future excavation or scour of 30 percent of total depth on one side of the structure. The designer shall, as a minimum, demonstrate by analysis that under this condition the structures will remain stable with an adequate margin of safety.

12.11.2.6 Earth Pressure

A. <u>Vertical Earth Pressure</u>

Depth of cover shall be measured from the ground surface or roadway crown, or from the street grade, whichever is higher, to the top of underground structure surface. Saturated densities of soils shall be used to determine the vertical earth pressure. Recommended values shall be presented in the Geotechnical reports described in the *Geotechnical* chapter.

B. <u>Lateral Earth Pressure</u>

For the purpose of these criteria, cut-and-cover box sections are defined as structures with stiff walls, which are restrained at the top so that the amount of deflection required to develop active pressure is not possible. See the *Geotechnical* chapter for earth pressures required for design.

12.11.2.7 Hydrostatic Pressure (Buoyancy)

The effects of hydrostatic uplift pressure shall be considered whenever ground water is present. The hydrostatic uplift pressure is a function of the height of water table above the foundation plane, and shall be assumed uniformly distributed across the width of the foundation in proportion to the depth of the base slab below the design ground water table.

Structures shall be checked for both with and without buoyancy to determine the governing design condition. Maximum design flood levels are indicated in the Hydrology Report. If the Hydrology Report is not part of the preliminary engineering documents provided by the Authority, the Designer (or its Geotechnical Engineer) shall determine applicable levels.

12.11.2.8 Flotation

For design flood levels and flood zone, see the Hydrology Report, if applicable.

Cut-and-cover structures subject to ground water table and/or located within the flood zone shall be checked and provided with adequate resistance to flotation.

No permanent dewatering system shall be assumed for the design of underground cut-and-cover structures.

A. Factor of Safety

The structure shall have a minimum factor of safety against flotation at any construction stage of 1.05, excluding any benefit from skin friction from perimeter of the structures.

The structure, when complete, shall have a minimum factor of safety against flotation at up to the 100-year flood level of 1.10 excluding skin frictional from perimeter of the structures.

The use of tiedowns, tension piles or other elements specifically designed to resist uplift forces shall be permitted and included in the flotation calculations. See *Geotechnical* chapter for other requirements buoyancy resisting elements.

The dead weight of the structure used in the flotation calculations for the underground structures shall exclude the weight of:

- Any building above the structure,
- Any live load internal or external to the structure,
- Any loads which is not be effective at the time, and
- 2 feet of backfill over the roof except when checking against the 100-year and 500-year flood levels.

12.11.2.9 Miscellaneous Loads

A. Cut-and-Cover Walkway Cover Live Loads

Stationary and hinged cover assemblies shall be designed for the loads on walkways per Section 12.7.1.4. Deflection at center of span under 100 pounds per square foot uniform live load shall not be more than 1/8 inch. Hinged cover material shall comply with NFPA 130 requirements.

B. Live Loads and Equipment Loads for Ventilation Structures

See Section 12.7 – Structural Design of Surface Facilities and Buildings, for roof and floor live loads and equipment loads for ventilation structures.

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12.11.2.10 Seismic Design of Underground Structures

See the *Seismic* chapter for the demand requirements for seismic design of tunnels and underground structures. If ductility is required to meet seismic demands in underground structure, then the requirements provided in CSDC for lateral confinement reinforcing of concrete pier walls shall be satisfied.

12.11.2.11 Reinforced Concrete Box Station Sections

Underground station structures and their appurtenant structural elements such as entrances shall be designed in accordance with AASHTO LRFD with Caltrans Amendments referenced AASHTO specifications.

Subsurface exploration shall be carried out to determine the presence and influence of geologic and environmental conditions that may affect the performance of station structures and reported by one or more Geotechnical reports described in the *Geotechnical* chapter.

- Load combinations and load factors to be used are those provided in this chapter. Load resistant factors to be used are those provided by AASHTO LRFD with Caltrans Amendments and their referenced AASHTO Tables 3.4.1-2, 3.4.1-3, and 12.5.5-1. In addition, the effects of EH, EV, ES, LS, DD, DW, and WA shall be applied simultaneously in all their maximum and minimum values to produce the envelope of moment, torsion, shear, and axial force to produce the greatest demands to the structural framing. These load values shall cover the forces on the station structure at all phases of construction. See AASHTO LRFD with Caltrans Amendments Section 5.14.2.3.
  - Final ground induced pressures and design assumptions for soil-structure interaction shall be provided by the Geotechnical reports described in the *Geotechnical* chapter.
- Vertical pressure on foundation slabs may be divided into hydrostatic and earth pressure components. The hydrostatic component shall be distributed across the width of the foundation in proportion to the depth of each portion of the basic slab below the design groundwater table.
  - Distribution of the earth pressure moment shall be based on specified construction procedures, and will include elastic and plastic subgrade reaction foundation effects.
- For design, the horizontal earth pressure distribution diagram for multiple braced flexible walls shall be the trapezoidal pressure diagram as given by the Contractor's Geotechnical Engineer. Compression forces shall not be considered in shear design of the top and bottom slab in box sections.

12.11.2.12 Reinforced Concrete

Concrete for cut-and-cover structures shall be designed to attain the required chemical resistance to the environment, low permeability, water tightness and water absorption as specified in accordance with the Durability Report.

Concrete mixes shall be tested for acceptance by the selected Quality Assurance organization in accordance with the Quality Assurance Plan procedures to conform to the requirements.

Concrete for cut-and-cover structures shall also meet the requirements of the Standard Specifications, and the following minimum requirements:

- Strength – Minimum f'c shall be 4000 psi at 28 days.
- Proportioning Materials – The maximum water-cement ratio shall be 0.40 with 4.5 percent to 7.5 percent air entrainment.

12.11.2.13 Reinforcing Steel

Reinforcing steel in structural components shall use Customary U.S. Units, meet the requirements of the Standard Specifications, and meet the following requirements:

- Use reinforcing steel conforming to ASTM designation A 706 Grade 60 (F_y=60 ksi).
- Use uncoated reinforcing steel and welded wire fabric when the concrete surface is not in contact with soil/water (or waterproofing).
- Use epoxy coated reinforcing steel meeting the requirements of the Standard Specifications for all permanent concrete members when the concrete surface is in contact with soil/water (or waterproofing).
- Spacing of main reinforcement shall not exceed 12 inches.

12.11.2.14 Camber

The tunnel roof shall be cambered to mitigate the effect of long term loads (i.e., slab plus backfill). The camber shall be calculated in accordance with the AASHTO LRFD with Caltrans Amendments, Article 5.7.3.6. In computing the long-time deflection it shall be no less than the immediate deflection multiplied by a factor of 2.

12.11.3 Waterproofing of Underground Station Structures

Roofs, walls, and floors slabs of underground station including auxiliary spaces except as otherwise noted, shall be waterproofed. To ensure adequate inspection and long term performance, no blind side waterproofing shall be used.

Provisions shall be made to collect and drain water potentially seeping through the roof, walls, or floor. The leakage through structural elements shall be limited to a maximum of 0.001 gallon per square feet of structure per day, and no dripping or visible leakage from a single location shall be permitted.

The manufacturer and installer of the waterproofing system shall submit a list of a minimum of five successful projects of similar design and complexity completed within the past five years.

The designer shall design for any openings or other penetrations through the waterproofing layer and for appropriate protection measures for the waterproofing membrane including the

chamfering of corners of the structure, external protection, etc. Components of the waterproofing system shall comply with applicable Volatile Organic Compound (VOC) regulations.

12.11.3.1 Underground Station Structures

A. Roofs

Station roofs shall be completely waterproofed. Waterproofing and the boundary condition details at reglets and flashings shall be provided.

B. Walls

Exterior station walls shall be completely waterproofed. Mezzanine walls enclosing public areas and entrance walls shall be furred out, and provisions shall be made for collecting and draining seepage through these walls. The depth of the furring shall be governed by the space required for the placing of fare collection and other equipment, and architectural requirements, such as the minimum thickness of the wall finish. The fastening of the finish to the wall shall be such that water can drain off the walls freely and that it will not corrode the fasteners.

C. Floor Slabs

For station floor slabs, no special waterproofing provisions shall be made where the water can drain freely into the floor drainage system, and where such a leakage and drainage is not objectionable from a corrosion, operational, or visual standpoint.

Drainage shall be provided at public areas of the station floor slab.

D. Base Slabs

Waterproofing shall be applied under station base slab.

E. Appendages

Differential vertical movements of the station body and its appendages, such as wings or entrances at shafts, due to ground re-expansion as a result of returning of ground water, may cause cracks at joints and other locations. Special attention shall be given to design detailing to mitigate this problem. Where such movements cannot be avoided, properly designed waterproof joints between such appendages and the station body shall be provided.

12.11.3.2 Cut-and-Cover Underground Trackway Structures

A. Cut-and-Cover Box

Exterior membrane waterproofing shall be applied to the outside of the cut-and-cover box as indicated on the Standard and Directive Drawings. Any seepage through the walls or the floor shall be carried away by the track drainage.

B. Transition Structure

For underground structure daylight transition structures, where U-sections or trenches with exposed sidewalls are used, special attention shall be given to controlling shrinkage cracks in sidewalls between construction joints.

C. Rooms

The following rooms or spaces shall be completely waterproofed, including all wall and roof surfaces in contact with the earth. Floor drains shall be provided. Refer to the *Mechanical* chapter.

- Electrical Rooms (includes spaces that house train control facilities, substation facilities, switchgear, ventilation fans, pumps, and other electrical equipment)
- Train Control and Auxiliary Equipment Rooms
- Substation , Switchgear, Fan Rooms, and Similar Equipment Rooms

D. Pump Rooms

Floor drains shall be provided to prevent the accumulation of seepage as required in the *Mechanical* chapter.

E. Cross-passages and Emergency Exits

Cross-passages shall be provided between tracks at every 2500 feet.

12.11.3.3 Waterstops and Sealants

Waterstops and sealants shall be used in construction joints in exterior walls, floors, and roofs.

12.11.3.4 Waterproofing Materials

Bentonite waterproofing shall not be used.

12.11.3.5 Water tightness

The cut-and-cover structure shall be designed and constructed so that it achieves a functional waterproofed underground structure for the duration of its design life. The design, construction, and maintenance of the cut-and-cover structure shall meet the water-tightness criteria stipulated below until substantial completion and acceptance by the Authority:

- Local infiltrations limit 0.002 gallons per square foot of structure per day and no dripping or visible leakage from a single location shall be permitted.
- No drips shall be permitted overhead or where they have the potential to cause damage to equipment, malfunctioning of any electrical power, signaling, lighting, control, communication equipment, or compromise electrical clearances.
- A drainage system shall be provided to accommodate water infiltration as specified herein in accordance with tunnel and portal drainage.
- No water ingress shall cause entry of soil particles into the tunnel.
- No material used in preventing or stemming water ingress shall compromise the fire safety of the works or the durability of the structures in which they are used.

- Embedded electrical boards, electrical conduits, and other similar elements shall be completely waterproofed and watertight.
- The interface between cut-and-cover structure section with bored tunnel and other structures, (i.e., building structures, emergency egress structures, etc.) shall be designed and constructed such that the joint between the two structures is fully watertight.

12.11.4 Water Holding and Conveyance Structures

Water conveyance or water holding structures that cross the HST alignment shall be designed to meet ACI 350 Code Requirements for Environmental Structures and Commentary with all Errata. The jurisdiction owning or operating the facility may have additional requirements that shall be followed.

12.11.5 Shoring Systems

For specific requirements of soil loadings see the *Geotechnical* chapter. The design of the support system shall consider several factors, including, but not limited to the following:

- Soil and groundwater conditions
- Width and depth of excavation
- Configuration of the structure to be constructed within the cut
- Size, foundation type and proximity of adjacent structures
- Utilities crossing the excavation, or adjacent to the excavation
- Requirements for traffic decking across the excavation
- Traffic and construction equipment surcharge adjacent to the excavation
- Settlements of adjacent structures
- Noise restrictions

12.11.6 Structural Fire Resistance

Underground structures can be exposed to extreme events such as fires resulting from incidents inside the structure. Underground structure design shall consider the effects of a fire on the concrete supporting elements. The concrete elements should be able to withstand the heat of the specified fire intensity given in the *Tunnels* chapter and period of time without loss of structural integrity. Protection from fire shall be determined by concrete cover on the reinforcing, additional finish, and special treatment of the concrete mixes.

12.12 Support and Underpinning of Structures

This section includes design requirements for the support and underpinning of existing structures to remain over or adjacent to new HST facilities.

The designer, in coordination with the Authority, shall investigate existing structures, which are to remain over, or adjacent to, the construction sites of new HST facilities. The designer shall prepare the necessary designs for the protection or permanent support and underpinning of such existing structures.

The types of buildings and structures, which require support and underpinning, include the following:

- Buildings and structures that extend over the HST structures to such an extent that they must be temporarily supported during construction and permanently underpinned.
- Buildings and structures immediately adjacent to the HST structures that will require temporary support during construction.
- Buildings and structures that are affected by groundwater lowering. In certain areas, uncontrolled lowering of the groundwater for HST construction can cause settlements of buildings either adjacent to or at some distance from HST excavations.

The design shall conform to the applicable requirements of the AASHTO LRFD with Caltrans Amendments (where highway bridges are involved), AREMA (where railway bridges are involved), CBC (where buildings are involved), ACI, AISC and AWS except where such requirements conflict with the criteria.

12.12.1 Depth of Support Structures

Underpinning walls or piers which support buildings or other structures and which also form a portion of the excavation support system shall extend to a minimum depth of two feet below the bottom elevation of the excavation.

12.12.2 Methods

Methods used to protect or underpin buildings or other structures shall take the site-specific soil conditions into consideration.

12.12.2.1 Protection Wall Method of Structure Protection

Under some soil conditions, the supporting system for the excavation is sufficient to protect light structures. Under heavier loading conditions, a reinforced concrete cutoff wall, constructed in slurry-filled trenches or bored pile sections braced with preloaded struts, may be considered as an alternative to underpinning or as a means to avoid settlement due to dewatering.

12.12.2.2 Stabilization of Soil

Soil stabilization techniques such as compaction grouting may be considered as alternatives in lieu of underpinning. Refer to *Geotechnical* chapter for soil stabilization.

12.12.2.3 Temporary Bracing Systems

A tight bracing system is important for the effectiveness of underpinning and for protection wall support. In addition to the general requirements for support of excavations, which are provided in the specifications, the designer shall indicate special requirements for the installation and removal of the temporary bracing systems that relate to the designs of underpinning and protection walls, such as the levels of bracing tiers, the maximum distances of excavation below an installed brace, and the amount of preloading. The designer shall require that detailed design of the temporary bracing system be the responsibility of the contractor. Refer to the *Geotechnical* chapter for earth pressures.

12.12.2.4 Pier, Pile, or Caisson Method of Underpinning

If soil conditions, structure size and proximity to an excavation dictate piers, piles or caissons for underpinning of an existing structure, such piers, piles, or caissons shall extend below a sloping plane which is defined as follows: The plane passes through a horizontal line which is located two feet below the bottom of the excavation, and which is also located within the vertical plane containing the face of that excavation closest to the structure foundation to be underpinned; the plane shall slope upwards and away from the excavation at an inclination which shall be established by the designer, on a case-by-case basis. The supports shall be founded on stable soil mass and extended beyond the slope of the soil wedge failure plane. Refer to the *Geotechnical* chapter for soils information.

12.12.2.5 Temporary Shoring and Underpinning

For temporary shoring and underpinning of the existing operating structures, seismic loads shall be considered in the shoring and underpinning design. The soil and inertia lateral seismic design loads shall be determined by geotechnical engineers using requirements. For seismic requirements of temporary shoring and underpinning, see the *Seismic* chapter. Shoring shall be required to maintain at-rest soil condition and monitored for movement.

12.13 Areas of Potential Explosion

Areas of new buildings adjacent to facilities where the public has access or that cannot be guaranteed as a secure area, such as parking garages and commercial storage and warehousing, shall be treated as areas of potential explosion.

NFPA 130, Standard for Fixed Guideway Transit and Passenger Rail Systems, life safety separation criteria shall be applied that assumes such spaces contain Class-I flammable or Class-II or Class-III combustible liquids. For structural and other considerations, separation and isolation for blast shall be treated the same as for seismic, and the more restrictive requirement shall be applied.

12.14 Structure Interface Issues

The design of aerial structures shall accommodate the requirements for safe operation of trains. Design of structures shall provide for interface with all other design elements.

12.14.1 Cable Trough

A cable trough shall be provided on both sides of the trackway. The cable trough shall be continuous through the entire system. The top of the cable trough shall be used as a safety walkway as a non-skid surface is provided.

12.14.2 Grounding and Bonding

Refer to the *Grounding and Bonding Requirements* chapter for grounding and bonding design of structures including, but not limited to the following:

- Aerial structures and bridges
- Trenches and retaining walls
- Cut-and-cover structures
- Buildings and support facilities
- New and existing third party structures
- Miscellaneous structures (e.g., cable trough, sound wall, etc.)

12.14.3 Drainage

Water shall be drained from the trackway and conveyed to the drainage system. See the *Drainage* chapter for drainage requirements.

12.14.4 Conduit Risers

Provisions shall be made for the installation of conduit up the sides of specific columns of aerial structures, walls of earth retaining structures, and walls of cut-and-cover structures. Further, details shall be provided for the installation such that no damage is inflicted on the columns, parapets, or walls.

12.14.5 Embedded Conduits

Sleeves shall be embedded in the cable trough and parapet to provide routing for future electric cable installation.

12.14.6 Trackside Equipment

Provisions shall be made to support trackside equipment. This equipment shall be located in line with the OCS poles.

12.14.7 Access Stairs

Access stairs shall be provided to the trackway from the ground surface in trenches, retained cuts, and cut-and-cover structures. The stairs and entrances shall be secured with fences and gates described in the *Civil* chapter. Minimum width of access stairs shall be 5 feet.

12.14.8 Overhead Concrete Anchors

These criteria apply to anchors for overhead applications and subjected to sustained tensile loads where failure of the anchor could result in risk to life or limb.

Anchors shall be embedded in confined concrete. Length of embedment in unconfined concrete shall not be considered effective embedment length.

Use of adhesive anchors in overhead applications or in sustained tension is prohibited.

12.14.9 Utilities

For utility requirements within HST structures, refer to the *Utilities* chapter.

Chapter 13

Tunnels

HSR 13-06 - EXECUTION VERSION

Revision	Date	Description
0	02 Mar 12	Initial Release, R0

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Acronyms

ACI	American Concrete Institute
ANSI	American National Standards Institute
ATC	Automatic Train Control
CIRIA	Construction Industry Research and Information Association
FHWA	Federal High
HST	High-Speed Train
M&E	Mechanical and Electrical
NFPA	National Fire Protection Association
OCS	Overhead Contact System
OD	Outer Diameter
SCS	Signaling and Communication Systems
TPF	Traction Power Facility

13 Tunnels

13.1 Scope

This chapter provides design criteria for bored tunnels, mined tunnels, and shafts and includes cross-sectional area requirements, structural design of tunnels and other underground structures, requirements at portals, and aerodynamic requirements. Refer to the *Structures* chapter for the design criteria of cut-and-cover structures. When referred to the *Structures* chapter, replace cut-and-cover structures with bored/mined tunnel.

This document applies to the design of new structures only.

13.2 Regulations, Codes, Standards, and Guidelines

Refer to the *General* chapter for requirements pertaining to regulations, codes, and standards. Key resource materials providing guidance useful for tunnel design and construction issues include:

- NFPA 130, Standard for Fixed Guideway Transit and Passenger Rail Systems, 2010 Edition
- California Code of Regulations (CCR), Title 8, Chapter 4, Subchapter 20 – Tunnel Safety Orders
- California Public Utilities Commission (CPUC) General Orders (GOs), Public Utility Codes, Rules of Practice and Procedure, and the Policies and Guidelines
- International Union of Railways (UIC), 779-11R – Determination of Railway Tunnel Cross-Sectional Areas on the Basis of Aerodynamic Considerations
- Federal Highway Administration (FHWA), Technical Manual for Design and Construction of Road Tunnels - Civil Elements, FHWA-NHI-09-010
- American Association of State Highway and Transportation Officials (AASHTO), Manual on Subsurface Investigations, MSI-1
- U.S. Army Corps of Engineers, Engineering and Design, Tunnels and Shafts in Rock, Manual No. 1110-2-2901
- Construction Industry Research and Information Association (CIRIA), Prediction and Effects of Ground Movements Caused by Tunneling in Soft Ground Beneath Urban Areas, CIRIA Funders Report CP/5
- California Department of Transportation (Caltrans)

  - Caltrans Highway Design Manual
  - Caltrans Project Development Procedures Manual
- American Railway Engineering and Maintenance of Way Association (AREMA) Manual for Railway Engineering

Approval is to be secured as required by the affected agency for which an exception is required.

13.3 Basic High-Speed Train Tunnel Configuration and Geometry

13.3.1 Train length

Tunnels shall be designed for train lengths of 660 feet to 1,312 feet with an additional 1 percent trainset length tolerance.

13.3.2 Train Operating Speed

Tunnels shall be designed to allow for train operations at speeds of up to 220 miles per hour (mph) (250 mph design speed).

13.3.3 Lining Type

The type of lining to be implemented for any particular underground structure shall be determined by the designer, provided that all performance criteria have been demonstrated to have been satisfied during the design process.

All tunnels and underground structures forming part of the permanent works may have structural lining consisting of one or more of the following lining types:

- Unreinforced or reinforced concrete cast in-situ lining
- Unreinforced or reinforced precast concrete segmental lining
- Reinforced sprayed concrete lining

13.3.4 Tunnel Configuration

The following tunnel configurations shall be considered:

- Single-track twin bored tunnel
- Single-track twin mined tunnel
- Twin-track single bored tunnel with a separation wall
- Twin-track single mined tunnel with a separation wall

Twin-track single bored/mined tunnel without a separation wall may be permitted at certain speeds and tunnel length subject to a design variance approval.

Fire- and life-safety and passenger-evacuation strategy must be considered when establishing the appropriate tunnel configuration.

13.3.5 Clearances

Required clearances to the High-Speed Train (HST) trackway and facilities are outlined in the *Trackway Clearances* chapter. Refer to the *Trackway Clearances* chapter for the static envelope, dynamic envelope, and fixed equipment envelope.

Standard Overhead Contact System (OCS) configurations are currently required in all tunnels. OCS configurations shall be evaluated where clearance in the tunnel is restricted.

Tunnel cross-sections shall accommodate intermediate and continuous tunnel facility equipment. Refer to the Standard and Directive Drawings for tunnel configurations and sizes and typical cross-section drawings.

The following continuous equipment may be located in the free tunnel cross-sectional area. The size of infrastructure is indicative.

- 6 x 6 inch outer diameter (OD) high voltage electric cables
- 10 x 3 inch OD low voltage electric cables
- 8-inch OD standpipe (fire line)
- 2-inch OD emergency air pipe
- 13-inch OD sump pump discharge pipe
- 1-inch OD leaky feeder cable
- 1-inch OD earthing tape and corrosion protection
- 2-inch OD handrail
- Tunnel air cooling circulatory water system (if required)
- Communications and signaling equipment
- Trackside concessionaire radio cables
- OCS and feeder wires
- System-wide safety ground conductor
- Dry standpipes
- Sliding crosspassage doors (only required in double track tunnels with separation wall between tracks)

If the total cross-sectional area of the equipment is undefined, a minimum allowance of 20 square feet shall be provided for assessing the minimum tunnel free cross-sectional area.

The following intermittent equipment may be located in the free tunnel cross-sectional area, and a space allowance shall be necessary outside the fixed equipment envelope. No allowance in the free cross-sectional area is necessary as the equipment is not continuous.

- OCS assembly
- Pulley wheels and mounting hardware for OCS
- Signage
- Tunnel walkway lighting
- Emergency radio antennae
- Fire telephone box
- Blue light station (at crosspassages)
- Rail lubricator tank
- Train control/signal case
- Fire extinguishers
- Fire isolation valves
- Ventilation equipment such as jet fans (if required)
- Low voltage disconnect switch and mounting hardware
- Trackside Automatic Train Control (ATC)/Communications equipment

See Standard and Directive Drawings for typical cross-sections with continuous and intermittent equipment.

13.3.6 Walkways

Each track shall be paralleled by 1 walkway along the full length of the tunnel. In the case of twin tunnels with a single track in each tunnel, the safety walkways will be located on the side of crosspassages. In the case of twin-track single tunnels with a separation wall, the safety walks shall be located on the side of the track adjacent to the separation wall.

The minimum walkway width shall be 3 feet and unobstructed to a height of 7 feet—6 inches.

The edge of walkway concrete shall be located at a lateral distance equal to 6 feet-11 inches from the track centerline and 9 inches vertically above top of rail to ensure dynamic clearance of the Rolling Stock. The distance from the walkway envelope to the track centerline has been set to establish the tunnel diameter consistent with the assumption that personnel shall not be in the tunnel outside the train during revenue operation.

No permanent or temporary obstacles such as pipes, conduits, lights, signs, signals or stored materials are permitted within the stated clearance.

Handrails shall be installed 3 feet-6 inches above walkway providing a route to a safe area. The handrail shall not interfere with the stated clearance envelopes, including the walkway clearance envelope.

13.3.7 Trackwork

The minimum depth at the track centerline from top of trackform to invert of bored tunnel shall be 3 feet. A direct fixation (non-ballasted) trackform is preferred in tunnels and is standard practice in new construction for rail tunnels due to its low maintenance requirements. Maintenance is a key consideration in tunnels due to restricted access, limited space for tamping activities, and short possession times.

13.3.8 Escape Shafts and Escape Tunnels

In twin-track tunnels without a separation wall, fire escape shall be self-assisted via walkways through a single lateral or vertical exit leading to the surface or other safe areas. Exits shall be spaced at distances along the running tunnel not exceeding 800 feet.

In twin-track single tunnels, at locations where vertical shafts cannot be provided such as under large water bodies or under mountains, a parallel service tunnel shall be constructed to the nearest vertical exit shaft. The passageways between the running tunnel and service tunnel shall be spaced at distances not exceeding 800 feet.

The minimum dimensions of the escape walkway shall be 6-feet wide by 7-feet-6-inches high. The minimum dimensions of the door opening shall be 6-feet wide by 7-feet-6-inches high. All exits shall be equipped with lighting and signs. Refer to Standard and Directive Drawings for details.

13.3.9 Crosspassages

Crosspassages shall have horseshoe-shaped cross-sectional profile.

In single-track twin tunnels, passageways between the tunnels shall be spaced at distances not exceeding 800 feet. The passageways shall be equipped with lights and signs.

Minimum dimensions of walkway envelope in the crosspassage shall be 6-feet wide by 7-feet-6-inches high. The minimum dimensions of the doors shall be 6-feet wide by 7-feet-6-inches high.

The crosspassages shall be furnished with lighting and signage.

There shall be adequate space in the invert of the crosspassages for drainage and cable trough(s).

Crosswalks shall be provided at each crosspassage location to allow for access between walkway and crosspassage. See *Civil* chapter for crosswalk configuration.

13.3.10 Equipment Requirements and Tunnel Niches

Arrangements and locations of the fixed equipments will vary at tunnel enlargements, niches, crosspassages and interfaces with other tunnel and structural sections.

Refer to Standard and Directive Drawings showing niche and recess details. Niches and enlargements present no difficulties in mined tunnels but may present a significant construction challenge in bored soft ground tunnels where groundwater pressure is present.

The effects of discontinuities introduced by the niches to the maximum pressure variation shall be taken into account during design.

13.3.11 Rolling Stock

Rolling stock profiles for candidate high-speed rail Rolling Stock were prepared to enable calculation of the cross-sectional area of the Rolling Stock. Refer to the Standard and Directive Drawings in the *Trackway Clearances* chapter. The information was derived from a variety of sources and requires verification following selection of the high-speed Rolling Stock. The cross-sectional area of Rolling Stock shall be relied on only for the purpose of calculating the free tunnel cross-sectional area required to comply with the Technical Specification for Interoperability (TSI) medical health criteria and aerodynamic drag calculations. When the HST Rolling Stock is selected, the free tunnel cross-sectional area calculations shall be finalized in accordance with the Rolling Stock criteria.

13.3.12 Aerodynamic Considerations

The design of tunnels and underground structures shall satisfy the Aural Comfort Criteria and the Medical Health Criteria as required by UIC 779-11R "Determination of Railway Tunnel Cross Sectional Areas on the Basis of Aerodynamic Considerations."

To satisfy the Aural Comfort Criteria, co-efficient of pressure tightness, , shall be no less than 25 seconds.

To satisfy the Medical Health Criteria, the maximum pressure variation in tunnels and underground structures along any train shall not exceed 1.45 psi during the time taken for the train to pass through the tunnel at the maximum permitted speed.

The maximum pressure variation in tunnels and underground structures for any train intended to run in the specific tunnel shall not exceed 1.45 psi during the time taken for the Rolling Stock to pass through the tunnel at a maximum speed of 220 mph.

The free cross-sectional area of the tunnel shall be determined so as to comply with the maximum pressure variation permitted, taking into account all the types of traffic planned to

run in the tunnel at the maximum speed at which the respective vehicles are authorized to run through the tunnel.

Features may be used on Rolling Stock and infrastructure, including sealing of Rolling Stock, closure of air conditioning inlets and outlets, tunnel entrance shape, shafts, etc., which reduce the pressure variation in the tunnel or the Rolling Stock to the allowable pressure variation of 1.45 psi.

The designer shall confirm the maximum allowable pressure variations and acceptable medical limits using acceptable, verifiable and certified data from existing revenue operation, trials, testing, research, Technical Specification for Interoperability, EN 14067: Railway Applications – Aerodynamics, UIC guideline 779-11R, and/or other equivalent or superior national and international codes, guidelines or practice.

The following programs may be used to aid the design process:

- SEALTUN – Used for the determination of a minimum cross-sectional area of railway tunnels for sealed trains based on the Aural Comfort Criteria and Medical Health Criteria.
- TRENDSHAFT – Used to show the influence of various numbers of airshafts on the maximum pressure changes for a large number of operating scenarios.
- DE-SHAFT – Used to calculate the indicative train pressures for tunnels with airshafts.

13.3.13 Minimum Tunnel Cross-Sectional Areas

The free cross-sectional area is defined as follows:

Free cross-sectional area = T - (RS + INV + FE + TOL)

Where:

T = the cross-sectional area of the tunnel

RS = the cross-sectional area of the Rolling Stock

INV = the cross-sectional area of the invert concrete

FE = the sum of the continuous fixed equipment area

TOL = the construction tolerance of the tunnel

Based on a sealed-train cross-section of 150 square feet and train length of 1,312 feet, and an unsealed-train cross-section of 140 square feet and (tunnel length/train length) ratio of 3.4, the following criteria shall be met:

- For single-track tunnel configuration, including double-track tunnel with separation wall where the operational speed is 220 mph (dedicated high-speed passenger train tunnels), the tunnel free cross-sectional area for each track shall not be less than 630 square feet.
- For twin-track tunnel configuration, including double-track tunnel without separation wall where the operational speed is 220 mph (dedicated high-speed passenger train tunnels), the tunnel free cross-sectional area shall not be less than 1,615 square feet.

13.3.14 Bored Tunnel

A circular cross-sectional profile shall be adopted for tunnel boring machine or shield driven tunnels. The main running tunnels shall be designed to be supported by precast concrete segmental linings or sprayed concrete lining installed as the excavation progresses. This excavation method shall be applied to underground excavations for which one or more of the following applies:

- Long tunnel drives
- In urban areas where ground settlement must be limited
- Tunneling in soft ground
- Tunneling in water bearing ground.

13.3.15 Mined Tunnel

A horseshoe-shaped cross-sectional profile shall be adopted for mined tunnels. This excavation method shall be applied to underground excavations for which one or more of the following applies:

- Openings are of short lengths
- Tunneling in conditions typically not deemed suitable for full face machine driven tunnels
- Tunnel cross-section is large
- Overburden is shallow
- Tunnel geometry is complex and includes construction of chambers, crosspassages, bifurcations, crossovers, widening and other transitional structures.

13.3.16 Transition between Cut-and-Cover and Bored Tunnel

The transition between the cut-and-cover and bored tunnel will introduce discontinuity on the surface of the tunnel. This discontinuity shall be eliminated through design or modeled in a program to confirm that it satisfies the Aural Comfort Criteria and the Medical Health Criteria.

13.3.17 Ventilation Shafts

The requirement for ventilation shafts is dependent on, but not limited to the following:

- Tunnel configuration
- Size and length of the running tunnels
- Type and frequency of the Rolling Stock
- Fire/Life Safety Strategy

13.4 Tunnel Portals

Portal design shall specifically take into account the following:

- Topographical conditions
- Geotechnical conditions
- Aerodynamic conditions (piston effects)
- Method of construction
- Environmental conditions
- Drainage

Wherever possible, tunnel portals shall be designed to minimize permanent cut slopes to limit the extent and scope of disturbance of existing ground conditions, including groundwater regimes and drainage, environment and visual aspects, and maintenance. This shall be achieved by construction of cut-and-cover structures and backfill to the original slope angle at bored or mined tunnel portals wherever the conditions in Section 13.15 allow.

Tunnel portals shall be designed to blend in with the surroundings.

13.4.1 Sonic Booms at Tunnel Portals

To mitigate aerodynamic effects, especially sonic boom, portal structures shall be inclined at least 45 degrees from the vertical. Where there are buildings near tunnel portals or there are special environmental requirements, portal hood structures shall be arranged in accordance with the requirements in Table 13-1.

Table 13-1: Requirements for Arrangement of Portal Hood Structure

Distance from buildings to tunnel portals	Are there any special environmental requirements for the buildings?	Monitoring point	Peak values of micro-pressure waves
Less than 150 feet	Yes	Building	As per the requirements
	No		=<0.42 lbs/ft^2
More than or equal to 150 feet	Yes	Places 70 feet from tunnel portals	<1.05 lbs/ft^2

The type and length of the trains, the length of the tunnels, the effective area of the clearances of the tunnels, the type of the tracks in the tunnels and the topographic conditions and the residential situations near the tunnel portals shall be taken into account in the arrangement of the portal hood structures.

The design of the portal hood structures shall comply with the following:

- The types of the hood structures shall be determined with a practical and aesthetic view and in accordance with the environmental conditions near the portals. Perforated hood structures that have the shape similar to that of the cross-sections of the lined tunnels shall be adopted.
- In case the cross-sections of the hood structures remain the same, pressure-releasing apertures shall be arranged on the side and top of the hood structures. The area of the pressure-releasing holes may be determined in accordance with the actual conditions and shall be 1/5 to 1/3 of the effective area of the tunnel clearance.
- Reinforced concrete shall be adopted for the hood structures.
- In case of tunnel portals where hood structures are to be arranged, retaining walls of the subgrade, if any, shall be placed beyond the scope of the buffer structures.

13.4.2 Portal Layouts

Portal infrastructure elements are described in Section 13.15.

Wherever possible, portal and shaft facilities, including ventilation buildings, shall be located away from the tunnel or shaft entrances so that if required, portal facilities can form separate construction contracts from tunnel construction. Portal facilities and tunnels construction shall then be carried out in parallel to optimize the schedules, to minimize knock on effect of delays, and to take construction interfaces off the critical path of construction activities.

In case of highways crossing over tunnel portals, the highways shall be provided with protection fences and monitoring devices.

In case the distance between the portals of two neighboring tunnels is less than 100 feet, the two tunnels shall be connected by an open tunnel.

13.4.3 Slope Failure or Landslide

Portal design shall minimize the risk of land slip and loosened soil or rock that may result in material falling onto the tracks at any time, including during a seismic event.

13.4.4 Unsymmetrical Pressure

Unsymmetrical pressure may act on the tunnel section and large stresses may develop. Measures shall be taken to balance the earth pressure by using counterweight fill or cut for slope stabilization.

13.4.5 Insufficient Bearing Capacity of Ground

The ground in the portal zone may consist of unconsolidated deposits or in weathered rock. Design shall ensure that there will be no excessive settlement or deformation at the portal zone due to insufficient bearing capacity.

13.4.6 Rock Fall or Debris Flow

The portal zone shall be located to minimize risk of rock falls and debris flows. When this is not practicable, adequate measures shall be taken to mitigate against rock falls and debris flows.

Rock fall and debris diversion or containment features (traps) utilizing trench excavations and berms shall be constructed to positively assure that no rocks, rock slides, or other debris such as soil or snow slides from mountain slopes above the portal area can reach the tracks or damage equipment or structures. Appropriate simulation software may be used to support determination of trench depths and fence sizes.

Where a portal opens directly from a very steep slope or cliff, such that a simple rock trap is not practicable, then the noise mitigation hood or other hood protection shall be extended far enough from the face of the cliff to protect the tracks and other structures. Protective structures shall be designed to withstand impact loads from all rock falls or slides that can be reasonably anticipated.

Each individual situation shall be evaluated through site-specific risk-assessment analysis.

See *Geotechnical* chapter.

13.4.7 Adjacent Structures

Impacts to the surrounding area as a result of construction activities (such as noise and dust) shall be considered when locating a portal zone.

13.5 Tunnel Ventilation Requirements and Configurations

13.5.1 Mechanical Ventilation

Mechanical tunnel ventilation shall be provided for tunnels longer than 600 feet for a trainset length of 660 feet or more.

13.5.2 Ventilation Configurations

Mechanical tunnel ventilation shall consist of one or more of the following configurations:

- Jet fans in the tunnel
- Axial fans located at tunnel portals
- Axial fans and saccardo nozzles located at tunnel portals
- Axial fans located at ventilation shafts or ventilation tunnels

13.5.3 Design Considerations

The mechanical tunnel ventilation configuration shall be defined for each tunnel by consideration of the following factors:

- Efficiency
- Maintenance
- Redundancy
- Reliability
- Fixed equipment and civil infrastructure (including access)
- Economics

13.5.4 Train Operation

For tunnel lengths of less than 6 miles, the following conditions shall be assumed:

- For twin bored or mined tunnels, one train is in each tunnel.
- For single mined tunnels with a separation wall (two train ways), one train is in each trainway.
- For single bored tunnels without a separation wall, one train is in the tunnel.

13.5.5 Maintenance Vehicles

The mechanical tunnel ventilation shall also be designed for the maintenance vehicles operating in or passing through the tunnel.

13.5.6 Access Shafts and Tunnels

If access shafts or tunnels are required by the tunnel ventilation design, these shall also be used, wherever possible, for mechanical tunnel ventilation.

13.5.7 Crosspassages

In order to prevent strong fluctuations of air movement while preventing internal re-circulation of air within the crosspassage, one side of a crosspassage shall be airtight during normal operation.

Materials

13.6.1 Concrete

Refer to the *Structures* chapter for reinforced concrete design requirements.

13.6.2 Structural Steel

Refer to the *Structures* chapter for structural steel design requirements.

13.6.3 Durability

Refer to the *General* chapter for the design life of structures.

The assessment shall consider the following factors that influence lining durability, including but not limited to the following:

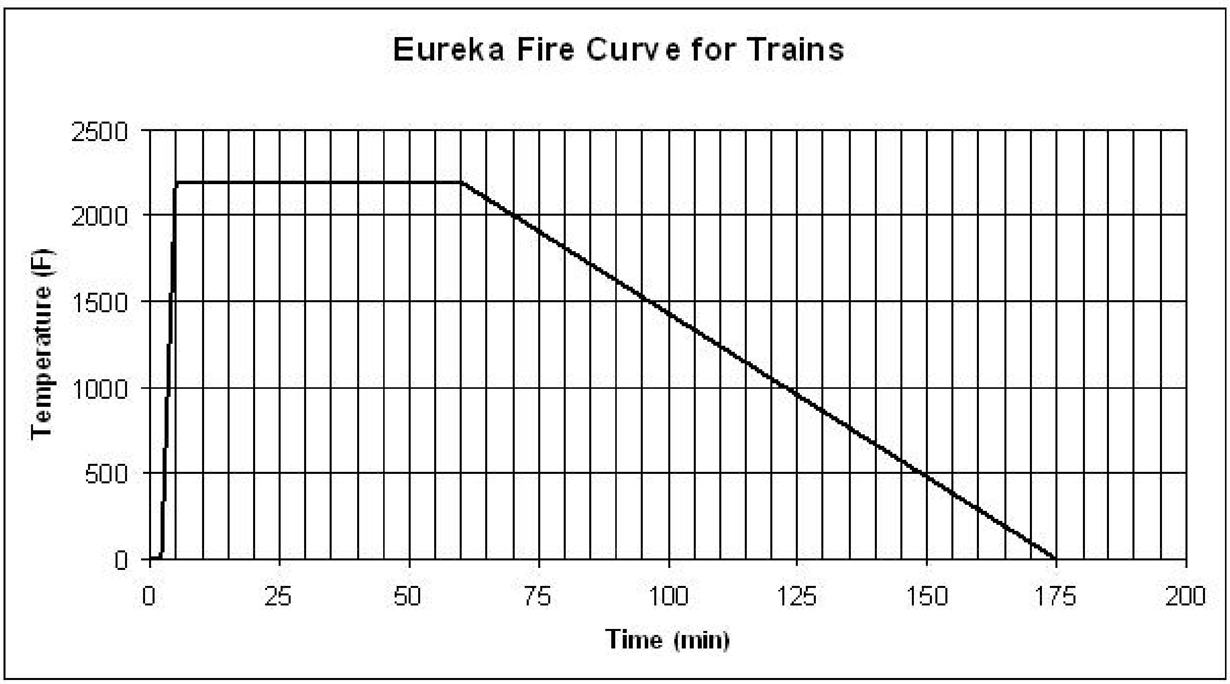
- Acid attack
- Chlorides and sulfate attack
- Alkali silica reaction
- Carbonation
- Watertightness
- Wetting and drying
- High ambient temperatures
- Stray current
- Cast in items and fixings
- Coating to reinforcement
- Water/cement ratio

- Gas and water permeability
- Corrosion protection
- Use of fiber-reinforced concrete
- Contaminated ground

13.7 Fire Protection

The fire performance of the finished tunnel surface shall withstand the temperature of the fire for a specified duration of time. The specified "temperature-time curve" is defined by the EUREKA Fire Curve for Trains in Figure 13-1:

Figure 13-1: EUREKA Fire Curve for Trains



Tunnels and underground structures shall be designed and constructed with non-flammable materials in accordance with NFPA 130.

Tunnels with precast, high-strength concrete elements shall be protected such that explosive spalling is prevented.

Walking surfaces designated for evacuation of passengers shall be constructed of noncombustible materials.

Remote vertical exit shafts and ventilation structures shall be not less than Type I (332) noncombustible construction as defined in NFPA 220.

Ancillary areas shall be separated from trainway areas within underground trainway sections by a minimum 2-hour fire resistive construction.

13.8 Design Loads

13.8.1 Design Load Considerations

The design shall be carried out by a consistent method using two-dimensional approximations or a three-dimensional analysis. However, the designer shall provide examples of where the method has been used before for tunnel design, and verification of the assumptions made about the behavior of the ground or the lining.

Live loads over the tunnel shall be considered when the depth of overburden is less than the tunnel width.

13.8.2 Ground Considerations

Refer to the *Geotechnical* chapter.

13.8.3 Groundwater Considerations

Tunnels shall be designed as undrained (i.e., with waterproofing) with the objective of eliminating impacts to groundwater and surface water resources due to groundwater drawdown. In the event that groundwater pressures are excessive, the designer may propose design alternatives to the undrained tunnel criterion. The designer shall demonstrate that their proposed alternative shall not impact the groundwater or surface water resources due to groundwater drawdown. Performance of equivalent designs alternative to an undrained tunnel shall meet criteria for protection of groundwater resources described herein and accepted by regulatory agencies having jurisdiction.

The groundwater data shall be used for the following:

- Design water management and dewatering programs
- Evaluate influences of dewatering on existing structures and on project excavations
- Evaluate impacts on surface and groundwater resources
- Determine water discharge volumes and treatment requirements (chemical)
- Calculate uplift pressures on excavations.

For further Hydrostatic pressure requirements, refer to the *Structures* chapter.

13.8.4 Seismic Load Considerations

Refer to the *Seismic* chapter.

13.8.5 Loading Combinations and Load Factors

Refer to FHWA-NHI-09-010 Road Tunnel Manual for the loading combinations and safety factors.

13.8.6 Aerodynamic forces

The design and installation of fixed equipment in tunnels shall take into account in combination with dead and live loads, the aerodynamic effect from passing trains, which produces a traveling wave of alternating pressure and suction along the tunnels.

Refer to the *Structures* chapter for Slipstream Effects (SS) Loads.

13.8.7 Flotation

Tunnels and underground structures shall be designed to resist flotation forces. The upper or lower bound of the groundwater level shall be taken into account in deriving hydrostatic loads, whichever is more critical for the structure or condition being considered.

13.8.8 Construction Methods

Segmental linings shall be designed for all handling, stacking, and erection forces with an allowance for impact or dynamic loading due to handling. Where it is proposed to use tunneling shields or machines, the lining shall be designed to resist all forces that may be applied by such equipment.

The distribution of ground pressures shall consider the probable construction method, the relative rigidity of the lining and the interaction of the lining with the ground. The design of tunnels in soil shall not allow for any long-term load relief by ground arching over the crown (i.e., full overburden pressure shall be assumed).

13.8.9 Temporary Structures

The design shall include an evaluation of all necessary temporary works and special construction techniques required as part of the construction of the permanent works.

13.8.10 Effects from Adjacent Structures

For surcharge loads due to adjacent buildings, refer to the *Structures* chapter.

Additional loads due to the driving of adjacent tunnels shall be considered.

13.9 Structural Analysis

13.9.1 Concrete Design

Refer to the *Structures* chapter.

In addition to dead, live, hydrostatic, and seismic loads in the permanent condition, concrete structures shall be designed for handling loads arising during manufacture and construction.

13.9.2 Steelwork Design

Refer to the *Structures* chapter.

In addition to dead, live, hydrostatic, and seismic loads in the permanent condition, steel structures shall be designed for handling loads arising during manufacture and construction.

13.9.3 Dynamic Analysis

The scope of the dynamic analysis shall include, but not be limited to, the following:

- Determination of vertical and horizontal modes and amplitudes of vibration in track support elements
- Identification of those modes and amplitudes of vibration that may be excited by the proposed Rolling Stock
- Estimation of the magnitude and frequency of the stress induced in the track support elements due to modes of vibration that may be excited by the proposed Rolling Stock
- Determination from the results of the dynamic analyses of the actual dynamic factors that are appropriate to be used in the design of the track support elements
- Estimation of the vertical and horizontal rail head accelerations

Both longitudinal and transverse structure geometry shall be analyzed and designed when considering dynamic effects.

13.9.4 Seismic Analysis

Refer to the *Seismic* chapter.

The additional earthquake forces shall be applied in conjunction with any pre-existing soil loads (active or at-rest as appropriate) and water loads if applicable. When deriving the dynamic component of earthquake load, the bulk unit weight shall be used for soil above and below water level since the pore water will move with the soil particles and experience the same acceleration.

Earthquake loading due to ground shear deformation from the bedrock motion shall be allowed for tunnels and underground structures.

13.9.5 Fatigue Analysis

For both concrete and steelwork structures, stress ranges induced by the Rolling Stock shall be combined with any other cyclic effects due to the Rolling Stock or other loading to which the structure may be subject when considering cumulative damage. Refer to the *Structures* chapter.

13.9.6 Mining in Rock

In accordance with Chapter 6 of FHWA-NHI-09-010, design of tunnels and other underground excavations in rock shall consider all potential rock stresses, failure modes, and difficult ground and any combination of conditions that can adversely impact tunnel construction and performance.

13.9.7 Tunneling in Soft Ground

In accordance with Chapter 7 of FHWA-NHI-09-010, design of tunnels and other underground excavations in soft ground shall consider excavation method, potential ground movement, type of ground support, and any combination of conditions that can adversely impact tunnel construction and performance.

13.9.8 Portals and Shafts

All cut slopes and excavations shall be designed for any possible mode of failure to meet minimum factors of safety that are 1.3 or greater for short-term construction (temporary slopes or construction slopes) and 1.5 or greater for permanent or final design slopes. These factors of safety shall apply to both soil and rock slopes for all portal and shaft excavations. The designer shall evaluate all ground conditions affecting stability of the portal or shaft that may include overburden excavation, weathered rock and unweathered rock in accordance with FHWA-NHI-09-010. The modes of failure shall be modeled using two-dimensional geologic cross-sections and/or three-dimensional modeling for use in conducting slope stability analysis using limit equilibrium methods outlined in the *Geotechnical* chapter to determine the factors of safety of each slope and slope support methods.

13.9.9 Enlargements

Enlargements shall be designed based on numerical methods. If enlargements are of complex geometry, three-dimensional analysis shall be performed.

13.10 Ground Movement

13.10.1 Purpose of Predicting the Ground Movement

The potential ground movement associated with the construction method shall be determined for the following purposes:

- To demonstrate that the environmental effects of the tunneling-induced ground movement have been considered and taken into account.
- To draw attention to those zones where the implementation of the design is likely to cause ground movement.
- To assess the risks of damage associated with the design, to investigate alternatives, and modify the design as necessary.
- If avoidance is not possible, to design protective measures against the likely damage, which measures could include settlement mitigation such as compensation grouting that could themselves have effects requiring assessment.

13.10.2 Method of Analysis

Settlement assessment shall be carried out in the following three phases:

- Phase 1 – The shape of the settlement trough resulting from tunneling activities shall be determined by empirical methods such as those described by CIRIA Funders Report CP5 using parameters for ground loss and trough width, which shall be determined from case histories, and taking into account the method of tunneling.

  All structures within the predicted zone of settlement shall be categorized by risk in accordance with the damage risk classification in Burland et al (1974). Any building or structure where the predicted settlement from tunneling is less than 0.4 inch and the predicted ground slope is less than 1/500 (equivalent to damage risk category 1 in Burland et al [1974]) shall not be subject to a further assessment. All other buildings or structures shall be subject to a Phase 2 assessment.
- Phase 2 – Buildings and structures subject to settlement, and falling under risk category 2 or greater (see Burland et al [1974]), shall be individually assessed using a limiting tensile strain approach as described by Burland et al (1974), and Boscardin and Cording (1989). Each structure shall also be subject to an inspection to determine its structural form and condition. Each building or structure shall be categorized into one of the damage categories in Burland et al (1974).
- Phase 3 – All buildings or structures that fall under risk category 3 or greater (see Burland et al [1974), following the Phase 2 assessment, shall be subject to further analysis and assessment using numerical analysis taking into account the soil–structure interaction. The response of such buildings and structures to tunneling induced settlement shall be assessed and appropriate preventative or protective measures identified.

13.10.3 Protection of Adjacent Assets

The design process shall include an assessment of the impact of construction on Third Party assets. In this respect, the designer shall assemble as far as reasonably practicable all available

records of foundations and other structures/artificial obstructions which could affect and/or be affected.

13.11 Measurement and Monitoring

13.11.1 Instrumentation and Monitoring Design

A system of instrumentation and monitoring of ground movement during construction shall be implemented appropriate to the ground conditions and the methods proposed for construction. The design shall include locations of instruments, frequency of monitoring, and how the monitoring will be used to control the construction progress. The following shall be carried out:

- Verify the predictive ground movement and the effects that such ground movement will have on adjacent assets by measurement.
- Establish monitoring base readings of the construction activity sufficiently in advance to ensure underlying and seasonal environmental trends are understood.
- If the results of monitoring indicate an issue, implement corresponding contingency plans.

13.12 Waterproofing

13.12.1 Requirements

Tunnels and underground structures shall be designed and constructed to be undrained. Provisions shall be made to facilitate repair or restoration to achieve a dry tunnel in the event that leakage occurs after construction.

Refer to the *Structures* chapter for waterproofing requirements.

13.12.2 Waterproofing Measures

The design of water resistance measures shall cater for the effects of long-term ground movements and movements associated with construction of adjacent structures. See *Structures* chapter.

Precast concrete lining shall consist of a gasket system.

Secondary linings such as in-situ concrete and sprayed concrete linings shall be protected by an external water resistant membrane, and construction joints shall be provided with water-bars.

13.12.3 Junction between New and Existing Structures

The junction between new and existing waterproofing is a potential source of leakage. The design shall take into consideration the following.

- New work shall be taken to a point that will provide a strong waterproof joint (i.e., the finished structure levels shall be the same to prevent a “well” or “dam” forming).
- The new and existing waterproofing shall be compatible. If the new waterproofing is a repair, then spray-applied membranes are recommended.

13.13 Drainage

13.13.1 Tunnels and Underground Structures

The internal drainage system shall collect condensation, leakage, spilled water, and other flows. The design shall provide space for the drainage system and the variation in position of the structure due to tolerances. Tunnel drainage sumps shall be provided at the lowest point of each section.

13.13.2 Portals

Adequate drainage shall be provided to ensure the stability of the slopes at the portal. Water from this drainage shall be directed away from the tunnel entrance.

Provision shall be made to safeguard against flooding from surface drainage and streams.

13.14 Special Ground Conditions

13.14.1 Design of Tunnels and Underground Structures

The design of tunnels and underground structures shall be based on the design parameters and groundwater levels presented and developed based on the Geotechnical Reports and new data obtained by the contractor.

The design issues related to special ground conditions are in addition to what is stated in the *Geotechnical* chapter.

13.14.2 Squeezing Ground

In the design and construction of the tunnels in squeezing ground, the distribution and characteristics of the ground shall be fully understood by a preliminary survey and testing before construction. Investigations, observations, and measurement shall be carried out during construction to allow appropriate measures to be taken.

The lining shall be shaped as close to circular as possible, and the perimeter of the cross-section shall be closed.

13.14.3 High-Pressure Water Inflows

In the design and construction of a tunnel to be excavated through ground where there is a risk of high-pressure water inflows in large quantities, an unexpected gush of water shall be avoided in assimilating results of investigations carried out before and during construction.

Where there is a danger of particularly large amounts of water inflow, the following measures shall be taken that are appropriate for the ground and aquifer:

- Drainage of water or lowering of the groundwater level
- Chemical injection, cement grouting or freezing of the ground to improve its properties, reduce permeability, and cut off the water

13.14.4 Gases Dissolved in Groundwater

In the design of tunnels through ground with a risk of gases dissolved in groundwater, a comprehensive investigation of the topography, geology, and groundwater shall be carried out during design.

13.14.5 Geothermal Ground

In the design of tunnels through ground with high levels of geothermal energy, a comprehensive investigation of the topography, geology, and groundwater shall be carried out during design.

13.14.6 Gassy Ground

Gassy ground conditions shall be classified according to the definitions in CCR Title 8. The CCR-mandated actions for each tunnel classification shall be applied to design and construction. Poisonous and explosive gasses shall be anticipated and evaluated in all areas of petroleum-bearing geologic materials, especially within or near known active or abandoned oil fields.

13.14.7 Rock Bursts

For the design of tunnels and underground structures located where there is a high risk of rock bursts, an investigation shall be carried out in advance so that any necessary precautionary measures can be taken.

13.14.8 Fault Zones

Horizontal and vertical alignment shall cross major fault zones at-grade without structures at active fault crossings where mitigating designs can be more cost-effectively employed. Faults shall be crossed perpendicular to reduce the extent of damage. However, for low slip rate faults and smaller displacements, normal tunnel design standards may accommodate limited fault displacement. The designer shall identify the presence of any major faults irrespective of age of

movement in that these zones will need to be evaluated from a seepage and boring condition standpoint.

Refer to the *Seismic* chapter.

13.14.9 Liquefaction

In areas where geotechnical investigation for the tunnels (or that of the planned or joint development construction) suggests a potential for the seismic consolidation or liquefaction of the soil, a special structural and geotechnical analysis of both designs shall be undertaken.

Evaluation of soil liquefaction triggering potential shall be performed in two steps. The first step involves evaluating whether the soil meets the compositional criteria necessary for liquefaction. For soils meeting the compositional criteria, the next step is to evaluate whether the design level ground shaking is sufficient to trigger liquefaction given the soil's in-situ density. If it is determined that liquefaction will be triggered, the engineering consequences of liquefaction shall be evaluated. In addition to Factor of Safety-based criteria for liquefaction, the design shall also consider the allowable deformation values and the long-term, post-construction performance requirements for earth and fill conditions.

13.14.10 Landslips

The designer shall identify and design for all existing and potential landslips that may impact the tunnel alignment, portal location, and design. In particular, allowances shall be made for mitigation measures such as real-time remote ground-movement monitoring, drainage, additional clearances, and repair of lining.

13.15 System-wide Interfaces

13.15.1 Catenary Support Provisions

Refer to the *Overhead Contact System and Traction Power Return System* chapters.

13.15.2 Warning Systems and Location Cases

Design of monitoring systems or detectors is required for the following hazards:

- Strong winds (*General* chapter)
- Snow and freezing conditions (*General* chapter)
- Heavy rain and floods (Track Level) (*General* chapter)
- Falling rocks (*Geotechnical* chapter)
- Landslide (*Geotechnical* chapter)
- Fault movement (*Geotechnical* chapter)

- Hazardous gas (*Geotechnical* chapter)

The designer shall advise on appropriate locations and design principles for these devices, depending on the details of the design. Refer to the *Supervisory Control and Data Acquisition Subsystems* chapter.

Devices—including items such as phones and other communication, seismographs, hot box detectors, dragging detectors, track crossing devices, emergency train stopping buttons, protection switches, intrusion detection, broken-rail detection, and other devices—shall be accommodated in the design. The designer shall allow for pre-embedded items, such as conduits, ducts, bolts, outlet boxes, as required for these devices.

Allowance shall be made in the design for foundations and fixation hardware for warning detector location cases.

13.15.3 Embedded Conduit and Cable Trough

Provision of embedments for installation of conduits and cable troughs shall be coordinated with the cableway design. Conduits shall generally be located across and below the trackway at locations of switch machines, at most equipment rooms for signals and controls, and at tunnel portals. See *Structures* chapter.

13.15.4 Facility Services and Infrastructure

An allowance shall be made in the design for the following wayside mechanical and electrical (M&E) systems:

- Lighting in tunnels and in tunnel access and egress locations (*Facility Power and Lighting Systems* chapter)
- Power receptacles in tunnels (*Facility Power and Lighting Systems* chapter)
- Emergency exit signs in tunnels (*Facility Power and Lighting Systems* chapter)
- General signage (*Civil* chapter)
- Telephones (*Communications* chapter)
- Ventilation systems in trainway tunnels, exit tunnels, and shafts
- Intruder alarm systems at exit tunnel doors
- Intrusion alarm system at portals
- Wayside devices to detect hazards on Rolling Stock (*Rolling Stock-Core Systems Interfaces* chapter)
- Gas monitors (*Geotechnical* chapter)
- Seismic monitors (*Seismic* chapter)

- Hoisting equipment in exit shafts (*Mechanical* chapter)
- Fire services provisions in tunnels (*Fire Protection* chapter)
- Power supply for all wayside M&E services (*Facility Power and Lighting Systems* chapter)
- Earthing/grounding and bonding requirements for all wayside M&E services (For cross-bonding requirements, refer to the *Grounding and Bonding Requirements* chapter)
- Communications (*Communications* chapter)
- Supervisory Control and Data Acquisition system (*Supervisory Control and Data Acquisition Subsystems* chapter)

13.15.5 Design Requirements for Cable Troughs

A cable trough is required along each track of the HST mainline.

The covers of the cable trough will form part of the walkway surface in tunnels. The cable trough covers shall be designed in accordance with the loads specified in the *Structures* chapter and *Civil* chapter. As the cable troughs will also act as part of the walkway, they shall provide an even, stable walking surface without creating a tripping hazard and have a non-slip surface.

Cable troughs shall have a spur at niche locations. These spurs shall have the same cross-sectional detail as the cable trough along each track of the HST mainline.

Cable troughs shall extend to crosspassages, shafts, and escape tunnels. These extensions shall have the same cross-sectional detail as the cable trough along each track of the HST mainline.

Cable troughs shall be drained. Typical details are shown on the Standard and Directive Drawings.

Where the cable trough transitions from outside of the tracks to the inside, the cable trough shall cross under the tracks perpendicularly with adequate space to accommodate minimum cable bend radii.

13.15.6 Fencing

AR Fences are required around tunnel portals and any other location where needed to prevent access by persons and large animals onto the tracks. The locations of the fences are shown on the Standard and Directive Drawings. Refer to the *Civil* chapter for details. AR fence shall conform to the Standard and Directive Drawings.

Wide gates providing access for emergency vehicles shall be installed at egress locations. Single or double gates shall be located where required for maintenance access. For each individual stretch of fencing, at least 1 gate on each side of the tracks is required. Gates shall require locks with a key for opening from the outside, but no key from the inside.

Fences shall be bonded and grounded in accordance with the *Grounding and Bonding Requirements* chapter and a continuity strap shall be carried below all gates to avoid the hazard of electric shock due to touch potential.

13.15.7 Prevention of Unauthorized Access

Design criteria for doors, gates and locking mechanisms required for the prevention of unauthorized access to emergency exits, rooms containing fixed equipment, corridors, stairwells and other controlled areas in tunnels, are described in the *Civil* and *Communications* chapters.

13.15.8 Grounding and Bonding

Refer to the *Grounding and Bonding* chapter.

13.16 Tunnel Portal Facilities

Portal infrastructure elements shall be evaluated for each portal of every tunnel used by HSTs. An assessment of items of portal infrastructure located at each portal shall be made based on tunnel configuration and portal locations.

13.16.1 Portal Infrastructure Elements

All infrastructure elements listed in Section 13.15 shall be considered and evaluated for potential inclusion at each tunnel portal in the HST system. Not all items are necessary at every portal. Following assessment, decisions shall be made on which items shall be located at each portal. Guidance on whether a particular element of infrastructure shall be included at a particular portal is provided in Section 13.16.

13.16.2 Noise Mitigation Hood

A noise mitigation hood is a smooth tapered hood (trumpet) designed to mitigate aerodynamic noise (sonic boom) effects. This hood may be up to 150 feet long.

The face of the hood-structure (if provided) shall be inclined at least 45 degrees from the vertical for noise mitigation purposes.

It is possible that tunnels more than 2 miles in length may need portal-hood structures at least 65 feet long designed for pressure-relief. This is in addition to the tapered section of the portal. Under these circumstances, the freecross-sectional area at the open end of the hood shall be at least 1.5 times the free-area cross-sectional area of the tunnel. Two pressure-relief openings (each of 108 square feet minimum area) are needed into each bore within the length of the pressure-relief structure. These openings vent into the adjacent bore or via ducts directly to the open air.

13.16.3 Portal Ventilation Building

Tunnel ventilation buildings shall be located at one or both tunnel portals.Portal ventilation buildings shall require direct access to the tunnels and shall be located immediately over or adjacent to the tunnel portals.

If practicable, buildings shall be designed to blend into the natural surroundings. Landscaped backfill and embankments with appropriate vegetation shall be employed. Refer to the *Stations* and *Structures* chapters.

13.16.4 Power Facilities

13.16.4.1 Traction Power

For Traction Power Facility (TPF) requirements, refer to the *Traction Power Supply System* chapter.

TPFs shall be located away from tunnels to the extent practical. It is preferred that substations and switching stations are located at least 2 miles from tunnel portals. If a TPF must be located near a portal, it shall be located no closer than 1 train length from an emergency vehicle assembly area. Alternately, if no space is available at the preferred locations, TPFs may be located in a shared-use building at the tunnel portal.

13.16.4.2 Fixed Facility Power

High or low voltage power is required to operate fixed tunnel and tunnel portal infrastructure. For preliminary design and to assure that reasonable, maximum-conceivable space requirements are identified, fixed facility power shall be located in a shared-use building facility constructed above or adjacent to the tracks at the tunnel portal. This building may also include tunnel maintenance and other facilities. Heavy equipment such as transformers and generators may be housed separately at ground level, with working access to the site access road to better accommodate installation and future replacement. See *Facility Power and Lighting Systems* chapter.

13.16.5 Access Road

Road access to portals shall be considered for use by emergency responders, for evacuating passengers and for maintenance staff access. Refer to the *Civil* chapter

If a TPF is located in proximity to a tunnel portal where road access has been established for other purposes, the TPF may make use of the same access road.

13.16.6 Emergency Vehicle Assembly and Turnaround Area

Assembly and turn-around areas for emergency vehicles shall be provided adjacent to the tunnel portal, at the end of the access road within the fenced portal area.

13.16.7 Rescue Area/Passenger Assembly Area

A rescue area/passenger assembly area shall be provided as close as practicable to the tunnel portal. Refer to the Standard and Directive Drawings.

13.16.8 Fire Hydrants and Water Supply

A water supply for tunnel fire-fighting purposes shall be provided to points near the emergency vehicle assembly areas. Refer to the *Fire Protection* chapter

Hydrants connected to adequate public water-supply systems or alternative permitted water supply of 60,000 gallons (minimum) shall be provided adjacent to the emergency vehicle assembly areas.

The water supply system shall be capable of providing a minimum of 500 gallons per minute at a residual pressure of 100 psi, for a period of at least 2 hours.

13.16.9 Area Lighting

Lighting systems shall be provided in order to maintain sufficient illumination levels at the ground surface of the portal site area during train evacuation. Refer to the *Facility Power and Lighting Systems* chapter

13.16.10 Cross Track Emergency Vehicle Access

If required, paved access roads shall be provided across the tracks for emergency vehicle use, which shall connect the emergency vehicle assembly area to each tunnel railway for emergency vehicle access to the tunnels. Refer to the *Trackwork* and *Civil* chapters. Automatic crossing warning devices are not required at these crossings as they are for emergency use only when revenue service has been halted.

Access areas for Hi-Rail emergency vehicles shall be provided.

13.16.11 Paved Emergency Egress from Tunnels

A well-lit paved walkway outside the tunnel portal shall connect the tunnel safety walkways to the passenger assembly/rescue area. Refer to the *Facility Power and Lighting System* and *Civil* chapters.

The emergency egress walkway at the portal facility shall have a minimum width of 10 feet.

13.16.12 Train Surface Evacuation and Fire Control Zone

A train surface evacuation and fire control zone shall be located outside a tunnel portal where a train exiting a tunnel under emergency conditions can stop to allow passengers to safely disembark, and may allow emergency responders to reach the train for fire-fighting purposes or to deal with other emergency situations.

13.16.13 Sound Powered Telephone Access, Emergency Intercoms, and Emergency Telephone Facilities

Sound Powered Telephone Access and Emergency Intercoms shall be provided within immediate proximity to the portal area emergency vehicle assembly and the passenger assembly/rescue areas. Refer to the *Communications* chapter.

Sound Powered Telephone Access at the portal shall be connected to Emergency Intercoms located within the tunnel and to the Operations Control Center.

Emergency Telephones shall be located adjacent to the motorized disconnect switches. Refer to the *Communications* chapter.

13.16.14 Overhead Contact System Motorized Disconnect Switch

Motor operated disconnect switches, equipped for local and remote operation, shall be provided for each OCS in close proximity to the tunnel portal for use by approved California High-Speed Train personnel. Motor operated disconnect switches shall be required at 3-mile intervals for tunnel length of more than 3 miles. Switch indication panels shall be provided at or adjacent to each switching location, indicating for the benefit of emergency response personnel the status of each switch and whether the OCS is energized/de-energized/grounded. A wayside power control cubicle shall be provided to support the disconnect switches, 10 feet by 8 feet in plan area. Refer to the *Overhead Contact System and Traction Power Supply System* chapter.

13.16.15 Emergency Command Post

An Emergency Command Post shall be located as close as practicable to the tunnel portal, emergency vehicle assembly area, and rescue area/passenger assembly areas.The Emergency Command Post location shall be well-lit using site area lighting. It shall contain an emergency telephone, OCS motorized disconnect switch remote control panel, Sound Powered Telephones, Tunnel Fire Alarm System Access, portal lighting controls and sufficient elements of a public address system to adequately support emergency responders.

A Ventilation Control Panel, which allows fire department personnel to ascertain the status and to operate the tunnel emergency ventilation system, shall also be installed at the Emergency Command Post, particularly if a portal ventilation building is not located at that portal.

13.16.16 Communications Facilities

All necessary facilities to support emergency and non-emergency communications transmissions between the portal area and HST operations (which might include radio, telephone, and fiber-optic cable capability) shall be provided. A Communications Tower may be required to assure reliable transmission. Refer to the Communications chapter.

13.16.17 Emergency Power Supply

Refer to the *Facility Power and Lighting Systems* chapter.

13.16.18 Surface Drainage

Surface run-off from disturbed site-areas shall be routed to a detention pond to prevent contamination of groundwater. Refer to the *Drainage* chapter.

13.16.19 Tunnel Seepage and Wash Water

Tunnel seepage water, wash water from any tunnel cleaning, and water from a fire-fighting incident, system test, or a pipe leak shall be routed through a detention pond or directly to a local sanitary sewer if available. Refer to the *Drainage* chapter.

13.16.20 Detention Pond

A detention pond of adequate size shall be constructed to handle run-off quantities calculated for the individual portal locations. Refer to the *Drainage* chapter.

13.16.21 Parking for Tunnel Maintenance and Traction Power Facility

Separate parking away from the emergency parking areas shall be provided for maintenance staff for tunnels and other site facilities. Refer to the *Civil* chapter.

13.16.22 Helicopter Landing Pad

In emergencies, medical/rescue aircraft or security helicopters may land on an emergency vehicle assembly area, another site parking area, or on the access road.

If a particularly remote portal area is identified where emergency access is required, but where road access is considered impractical, then a helicopter landing area shall be established.

13.16.23 Landscaping

Landscaping with backfilling, grading and vegetation shall be employed to help blend structures into the surrounding natural condition. Refer to the *Stations* and *Support Facilities* chapters.

Access shall be provided to allow maintenance of landscape vegetation.

13.16.24 Aesthetic Treatment of Rock and Concrete Surfaces

Freshly exposed rock surfaces in portal excavations planned to be left permanently exposed shall be treated to appear naturally formed and weathered.

In-situ concrete or sprayed concrete surfaces shall be colored and sculpted to blend into the surrounding landscape.

13.16.25 Public Utilities

Public utilities for servicing the portal site areas shall include water, electricity, telephones, and sewers. See *Utilities* chapter.

13.16.26 Crossovers

The proximity of crossover tracks to the different tunnel portals shall be assessed to ensure that single-track working can be maintained effectively through the tunnels during emergencies and when one tunnel railway is closed for major maintenance or repair.

13.17 Portal Infrastructure Requirements for Different Categories of Tunnel

Not every item of infrastructure described in Section 13.15 may be required at every HST tunnel portal. The following sections provide general guidance in determining which of these elements of portal infrastructure may or may not be required at a particular tunnel portal, or under certain circumstances, where some listed items of "portal" infrastructure may need to be located some distance from a portal.

The principal factors that influence the decision are the following:

- Length of tunnel
- Proximity of one tunnel to another
- Accessibility to portal locations
- Environmental impacts at a portal location

Any particular tunnel portal may have additional site-specific requirements.

13.17.1 A Shorter Tunnel up to One-Half Mile in Length

All infrastructure listed in Section 13.15 shall be considered to be located at one of the two portals of a tunnel.

Tunnel emergency ventilation is not required for tunnels up to 1/2 mile in length.

The following items shall be considered for both portals of a tunnel:

- Noise mitigation hood
- Intrusion protection fence
- Rock fall and debris containment
- Surface drainage

- Tunnel seepage and wash water (if downgrade from the other portal that was preferred for the principal infrastructure installations)
- Detention pond (if downgrade from the other portal)
- Area lighting (assumes temporary passenger assembly might be needed on the tracks outside the portal prior to relocating through the non-incident tunnel to the Rescue Area at the other portal)
- Landscaping
- Aesthetic treatment of rock and concrete surfaces
- Emergency telephone facilities
- OCS-motorized disconnect switches and indication panels

13.17.2 Several Short Tunnels Close Together

For a group of short tunnels close together, emergency access and egress and other portal infrastructure facilities (as listed in Section 13.15) that are provided for 1 portal of 1 tunnel shall serve the emergency requirements of several tunnels provided that:

- Such emergency facilities are spaced no further apart than 1 1/2 to 2 miles; and
- Emergency access and egress to required standards can be provided from the location where the emergency facilities have been located, along paved track-slab extending through and between the several tunnels, or along an adjacent roadway.

Other tunnel portals in the group of short tunnels shall consider the particular infrastructure items separately listed in Section 13.16.1.

13.17.3 Shorter Tunnel with Constrained Access

A shorter tunnel up to 1/2 mile in length with physical conditions at both portals that prevent construction of required permanent emergency access and egress infrastructure elements (Section 13.15), or where exceptional environmental conditions exist that render this construction unacceptable, shall require additional elements and considerations.

To serve the tunnel under these circumstances, all permanent emergency infrastructure elements listed in Section 13.15 shall be provided to each portal, or to a location along the track within 1/2 mile of each portal, provided that emergency access and egress to required standards can be provided to the tunnel from the location where emergency facilities have been located, along paved track-slab or along an adjacent roadway

At each portal, the following elements are required to be considered at the immediate location of the portal:

- Noise mitigation hood

- Intrusion protection fence
- Rock fall and debris containment
- Surface drainage
- Area lighting
- Landscaping
- Aesthetic treatment of rock and concrete surfaces
- Emergency telephone facilities
- Sound Powered Telephone
- Emergency Intercom
- OCS-motorized disconnect switches and indication panel

13.17.4 Tunnel Longer than One-Half Mile in Length

Infrastructure listed in Section 13.15 shall be considered for both portals, including the need for portal ventilation buildings at both portals. Tunnel seepage and wash water and detention pond requirements normally need to be considered only at the portal at lower elevation.

13.17.5 Longer Tunnel with Constrained Portal Access

Where a tunnel more than 1/2 mile in length has physical conditions at one or both of the portals that prevent construction of required permanent emergency access and egress infrastructure elements (Section 13.15), or where exceptional environmental conditions exist that render this construction unacceptable, the following shall be considered:

- All permanent emergency access and egress infrastructure elements (Section 13.15) shall be provided at an unaffected portal.
- All permanent emergency infrastructure elements (Section 13.15) shall be provided to each portal or to a location on the track within 1/2 mile of portals, provided that emergency access and egress to required standards can be provided to the tunnel along paved track-slab or along an adjacent roadway from the location where the emergency facilities have been located. Alternatively, emergency access and egress shall be provided via a mid-line tunnel rescue shaft or rescue tunnel located within 1/2 mile of affected portals.
- The infrastructure elements that are listed in Section 13.16.3 as requiring consideration at both portals of a shorter tunnel with constrained access similarly require consideration at both portals of a longer tunnel with constrained access.

A design variance is required if access to both tunnel portals cannot be provided.

Chapter 14

Stations

HSR 13-06 - EXECUTION VERSION

Revision	Date	Description
0	02 Mar 12	Initial Release, R0

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Acronyms

ADA	Americans with Disabilities Act
ADAAG	Americans with Disabilities Act Accessibility Guidelines
ANSI	American National Standards Institute
CBC	California Building Code
CCTV	Closed-Circuit Television
CHST	*Not Used; use HST for California High-Speed Train*
CHSTP	California High-Speed Train Project
HST	High-Speed Train
HV	high voltage
HVAC	Heating, Ventilation, and Air Conditioning
LEED	Leadership in Energy and Environmental Design
LOS	Level of Service
LV	low voltage
NFPA	National Fire Protection Association
OCC	Operations Control Center
OCS	Overhead Contact System
POL	Platform Occupant Load
ppm	people per minute
PSB	Passenger Service Booth
SCR	Station Control Room
TCF	Terminal Control Facility
TVM	Ticket Vending Machine
UPS	Uninterruptible Power Supply

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14 Stations

14.1 Scope

This chapter establishes the architectural design criteria for the California High-Speed Train (HST) stations, site design, and landscaping.

14.2 Regulations, Codes, Standards, and Guidelines

Refer to the *General* chapter for requirements pertaining to regulations, codes, and standards. This chapter presents design standards and guidelines specifically for the construction and operation of the high-speed railway based on international best practices and applicable state and federal requirements.

Since the stations will be located in multiple municipal jurisdictions, other transportation owner/operators' rights-of-way, and/or unincorporated jurisdictions, the CHSTP standards and guidelines may differ from local jurisdictions' codes and standards. Although state agency projects are not subject to local city or county codes, the HST System is to provide for connection and integration with other passenger rail and transit services as well as the surrounding station area. In the case of such connections, consideration of local codes and other transportation owner/operators' guidance is appropriate.

Applicable codes, rules, standards, and guidelines include but are not limited to the following:

- Code of Federal Regulations (CFR) Title 28, Part 36 – Nondiscrimination on the Basis of Disability by Public Accommodations and in Commercial Facilities
- California Building Code (CBC), Title 24 of California Code of Regulations (CCR)
- Americans with Disabilities Act (ADA)
  - ADA Standards for Accessible Design
  - Guidance on the ADA Standards for Accessible Design
  - ADA Accessibility Guidelines (ADAAG)
- National Fire Protection Association (NFPA)
  - NFPA 101 – NFPA's Life Safety Code
  - NFPA 130 – Standard for Fixed Guideway Transit and Passenger Rail Systems

- American National Standards Institute (ANSI) 117.1 – standard for accessible design for persons with disabilities
- California Division of the State Architect California Access Compliance Reference Manual

14.3 Stations

The purpose of this section is to set forth design guidelines and standards for passenger stations that promote safe, efficient, and high-quality operations for HST service. This section presents information relating to space requirements, building amenities, station performance, circulation, connection, and safety of the patrons and employees of the HST System.

14.3.1 Design Principles

There will be a high degree of variability between stations due to different locations, ridership demands, intermodal connections, trip purposes, and local land use. This section identifies minimum design criteria to be considered at HST stations.

14.3.1.1 General

The following principles apply to the design of all stations:

- **Safety –** Safety of station patrons, train passengers, and operating personnel shall be the first priority in station design.
- **Design Life –** Designing for the expected useful life of passenger stations is a fundamental design principle and is addressed in the *General* chapter.
- **Station Size –** Stations shall provide adequate space for all essential station functions including platforms, public circulation, passenger services, station operation offices, Core Systems and plant rooms, and special provisions at Terminal Stations.
- **Clarity –** Stations shall be organized clearly and simply. Passenger circulation routes shall be clearly identifiable and unobstructed.
- **Context –** Each station shall be responsive to its unique physical environment and context.
- **Structural Design –** Structural elements of stations shall conform to the requirements described in the *Structures* chapter.
- **Finish Materials –** Stations shall utilize finish materials that are durable, energy efficient, and easy to maintain.
- **Shared Use –** At special stations serving both high-speed and conventional rail services, shared use does not infer shared functions. Where multiple rail systems will be sharing an enclosure, functional, operational, and support facilities for HST shall be dedicated and shall not be shared with other operators.

- **Future Modifications –** Station design shall consider a "not to preclude" approach and provide sufficient flexibility to accommodate reasonable future updates to the programmatic requirements.

14.3.1.2 Architectural Design Principles

A. Introduction

While the majority of this chapter sets forth planning guidelines and technical requirements for HST stations, this section is intended to convey the more subjective and esoteric qualities and aspirations of station architecture. The architectural design philosophy and principles are provided to assist designers in developing station design solutions that achieve the objectives of the California High-Speed Rail Authority (Authority).

B. California State Excellence Standards

The CHSTP supports the broad goals set forth by the California Department of General Services (DGS) "Excellence in Public Buildings" (EIPB) program, which promotes "high-performing public buildings and a positive architectural legacy that reflects the State's commitment to excellence." (http://www.documents.dgs.ca.gov/dsa/pubs/eipb.pdf) This statement communicates the State's expectations in the building-delivery process. The program seeks to produce high-performing public buildings through "Excellence Goals," establishing objectives that promote design excellence, sustainability, enduring value, and public benefit.

The Authority supports the State's following "Excellence Goals" as a basic foundation by which the design of HST stations shall be measured:

- **Architectural Excellence –** Attract outstanding architects who are committed to design excellence, best practices in energy and environmental sustainability, and the other goals of EIPB.
- **Sustainability –** In accordance with Executive Order S-20-04, Leadership in Energy and Environmental Design (LEED) certification of Silver or higher shall be provided.
- **Integrating Art into Public Buildings and Spaces –** Expand the public experience with art while adding to the building's identity and enhancing the human experience.
- **Cost Effectiveness –** Use performance standards, life-cycle costing, and integrated design to deliver value above the initial financial investments.
- **Universal Design –** Enhance accessibility for all.
- **Safety and Security –** Safe and secure from natural or man-made disasters.
- **Make a Positive Contribution to the Local Community –** Buildings sited and designed to enhance the local built environment. This goal includes the following:
  - Involving community participation
  - Strengthening and revitalizing California's cities and communities
  - Enhancing the livability of the community

- Supporting economic renewal
- Encouraging multiple uses of public spaces
- Promoting use of public transportation
- Supporting sound growth patterns
- Providing convenient access for customers and employees
- Reducing traffic congestion
- Promoting improved air quality

- **Preservation of Buildings of Historic Value –** Preservation of historic buildings retains the art of architecture that has contributed to the community for decades.

C. System Design Philosophy

Objectives – The central objective for design of the HST System is to provide a safe, convenient, fast, and efficient means of travel to the users. A secondary fundamental design principle is to present a strong, positive image of the facilities to the citizens of California through excellent architectural design.

Image – Given the State's aforementioned design excellence principles as overarching guidance, the architectural image of stations and facilities will be of particular importance. As perhaps the nation's first high-speed rail system, the CHSTP will establish a standard of quality for many similar systems to follow. The utmost attention shall be paid to producing architecture commensurate with the overall project goals.

The stations will symbolize a new mode of travel and transportation for this nation, not unlike the great urban railway stations that have become the heart of communities throughout the world. Convenient interchange with other modes of transportation will be the catalyst in creation of successful transportation centers and development of communities in which they are to be built.

Character – The HST System will present unique challenges and architectural opportunities. High-speed rail has existed for decades in other parts of the world, but the system will present a new kind of silhouette upon California's architectural landscape; uncommonly long station buildings and frequent movement of trains will introduce an unfamiliar yet exciting visual experience. While each station will be expected to integrate the functional and safety requirements within the constraints of budget and schedule, each will be expected to convey a strong individual civic character, relating clearly and strongly to its context through careful architectural design.

D. Exterior Architectural Principles

Uniqueness – Because each community to be served by an HST station is unique, architectural design of each station will be unique. The specific functional needs of each station shall be wrapped with an architectural skin that is site-specific in scale, massing, volume, and material. Although certain internal and functional elements will be common to all stations, the high-

speed rail station image presented to each community will be a carefully considered response to the context of each station site.

Design Factors – Specific purpose, context, presence, and image shall be defined individually for each station. Each station shall respond to unique, site-specific design factors, including location, alignment, existing and future neighborhood architectural and historic context, anticipated ridership, climatic variations, vehicular and pedestrian station access, multimodal transfer, protection from the elements, passenger orientation, and familiarity, wayfinding, constructability and sustainability.

All of these unique, site-specific architectural and urban design considerations shall be synthesized into an architectural solution, and be responsive to the unique site and the strict operational and programmatic requirements.

Community Links – As a new focal point of the community, the planning and siting of the HST station shall convey an awareness of its prominent presence. It should not seek to dominate its neighborhood but rather to be sensitive to its community and context. Connections, entrances, and station access points shall respond to neighboring residential, commercial, or other uses. Edges of the station area should blend smoothly with the surrounding urban fabric and be responsive to each community's long-range urban development plans.

Massing – Vertical location of platforms, Concourses, and entrances will be a significant factor in the massing of each station; at-grade stations with an adjacent at-grade Concourse will convey a significantly different presence within an urban context than will an elevated station raised 60 or more feet above the street. This kind of inherent programmatic difference will be a driving influence in the presence of a station and in the architectural solution.

Style – Stylistic trends in early 21st century architecture will not remain constant; therefore, while each station shall reflect current and forward-thinking innovation, it shall avoid a design approach that may appear dated decades later. Station context and community concerns shall be reflected in station design. Where stations are to be located in established urban environments, the goal will be to transform and enhance that environment and community while protecting the neighborhood's fabric. Where station sites are to be located in sites without a strong existing character or context, the goal will be to establish a strong architectural foundation for future community growth.

Image – Railway stations are a unique building type with a unique purpose. The image of a station shall therefore convey the function of the building through its architectural design. A railway station should look like a railway station. As gateways to the HST System and to major metropolitan centers, stations will convey an arresting image. HST stations will symbolize and celebrate a new means of travel in America.

Context – Care shall be taken to be sensitive to the station context, recognizing that an architectural solution appropriate for a densely populated, established urban center may not be appropriate for a smaller suburban community. In many cases, subtlety and understatement

may be more appropriate than exhilaration and innovation. California has rich, diverse regional characteristics, which may be valid sources of local identity for stations. Sensitive architectural interpretation of these regional variations can contribute to an HST System representative of all regions that the system will serve.

Finish Materials – Exterior materials selected for stations shall be for the specific site context while satisfying system-wide design concerns, including safety, useful life, durability, low maintenance, replacement, and potential vandalism. Materials shall respond to the context of the site and convey stability, warmth, brightness, and quality.

Lighting – The presence of an HST station at night is no less important than during daylight hours. Prudent and dynamic use of lighting will be a significant design element in a station's nighttime presence. Station interior lighting shall be designed to create an inviting station presence when viewed from the exterior, while ensuring energy efficiency and satisfying sustainable design goals. Station sites, including parking, approaches, landscaping, signage, and entrances shall be appropriately lighted for user safety as well as for architectural effect.

E. Interior Station Design Principles

Station Volume – The greatness of railway stations in times past has often been the result of soaring station volumes. Similarly, upon entering an HST station, the patron will experience a sense of exhilaration, spaciousness, openness, clarity, and system identity. Entrances and Concourse spaces shall be generously and appropriately sized according to the specific functional needs of each station. At the same time, a striking architectural image shall be established through the judicious use of vertical space and interior volume. Ceiling heights may be modulated wherever the opportunity exists. Low ceilings may be used sparingly as an intimate contrast to the vertical volumes.

Openness – Station planning and design shall be founded upon uncomplicated and open concepts to facilitate free movement of passengers and staff. Adherence to principles of passenger circulation described in the following sections, particularly with respect to clear, unobstructed, well-defined, well-lighted routes for public circulation are essential to planning of public areas and passenger satisfaction.

Interior Lighting – Liberal use of natural lighting is a guiding principle for station interiors. Natural light creates drama within interior spaces as it changes constantly throughout the day. Openings that allow light into the station during the day contribute to a more dynamic station presence within the community at night. Artificial interior lighting shall be used judiciously to illuminate the functions requiring task and safety lighting and differentiating between differing station functions. Light sources and placement shall be attentive to the energy standards established by the State of California.

F. Sustainability and LEED Principles

Stations shall be, at minimum, LEED™ Silver Certified as described elsewhere in this Design Criteria.

14.3.1.3 Functional Design Principles

A. General

Specific functional requirements of station spaces are described in this chapter.

There is no single "footprint" that can be applied at each station site. Each station will be a response to essential functional relationships described in this criteria and adapted to the unique station site.

B. Consistency and Variability

Elements of station plans can be categorized as functionally consistent or functionally variable.

Consistency – System-wide, consistent use of design components in stations can result in reduced capital, operations, and maintenance costs through reduced design and construction variation, economies of scale, and simplification of operation and maintenance procedures. Functionally consistent elements include but are not limited to the following:

- Platform width and length
- Platform floor finish surface and edge material
- Station Information Office
- Ticket Sales Office location and identity
- Non-public area staff and plant room organization
- Fare collection equipment
- Escalators and elevators
- Passenger Information Systems, including signage and graphics
- Fire hose and extinguisher cabinets
- Door hardware

Variability – Varying station elements in addition to varying the architectural design approaches described in Section 14.3.1.2 Architectural Design Principles, responds to unique needs of individual stations. Functionally variable elements include the following:

- Concourse configuration
- Finish materials (in accordance with the CHSTP's acceptable palette)
- Interior seating
- Artwork
- Site layout, landscaping and site furnishings

C. Functional Types

Station functional type will significantly influence station planning and design. Stations are classified as intermediate or terminal types.

Intermediate Stations – Stations not functioning as terminals are considered Intermediate Stations. Passengers will typically wait on the platform prior to the train's arrival due to relatively short train dwell times. Signage shall inform passengers where to wait in order to quickly board the proper car when the train arrives.

Terminal Stations – Trains will occupy Terminal Station platforms for longer periods of time than will be the case at Intermediate Stations. Terminal stations shall require additional ancillary facilities to facilitate servicing trains prior to turning back. Terminal station platform activities may include provisioning onboard food service, light interior cleaning of the train, trash removal, train crew changeover, and light mechanical inspection. Refer to Section 14.3.6 for specific space requirements.

Key Intermediate Stations (with Turnback Service) – Key Intermediate Stations may have more extensive access to connecting feeder services or a higher level of ridership than regular Intermediate Stations, but less than that of Terminal Stations. In addition, during the early stages of the system phase-in, some trains will originate and terminate at these stations in order to optimize utilization of the train fleet. These stations may require some of the elements usually found at a Terminal Station, such as space for train crews to wait in between trains, and may have a higher level of customer services and amenities than regular Intermediate Stations.

14.3.1.4 Station Planning

Each station shall be planned and sized to accommodate projected ridership for both normal and emergency conditions. Spaces shall be sized and located for optimal functionality and efficiency, in accordance with the requirements described in this chapter.

Primary station zones include but are not limited to entrances, Free Area, passenger amenities, fare collection, Paid Area, platforms, passenger service areas, station operation offices, ancillary spaces, building Core Systems/plant spaces, and train servicing facilities.

A. General Planning Goals

Station planning goals include the following:

- Safety and security of station occupants
- Avoidance of passenger congestion and compliance with level of service objectives
- Adequate capacity for passenger surges or disruptions in train service
- Adequate emergency evacuation capacity
- Simple and clear passenger circulation within station and surrounding areas
- Unobstructed lines of sight and well-lit spaces

- Accessibility for all passengers
- Efficient and convenient interchange with other modes of transportation

B. Station Size

General – Every station comprises public and non-public functions and shall be planned individually to accommodate the functional needs for the specific location. Basic station components include the following:

- Platforms (size is a function of train length, vertical circulation and passenger circulation)
- Public Concourse (size is a function of ridership)
- Support Space (size is a function of staffing levels)
- Core Systems and Plant Rooms (size is a function of Core Systems equipment and plant rooms)

Platforms – Platforms are the key components for public access to trains. Platform size is a function of train length and width of escalators, stairs, and passenger circulation and will generally be unaffected by ridership. Size shall be sufficient for safe circulation of passengers on platforms during normal and emergency conditions.

Public Concourse – Public station areas within the Concourse and mezzanine intended for passenger circulation shall accommodate forecast ridership in the Full Build (2035) or projected Phase I, whichever is higher under estimated peak period and emergency conditions. Refer to the CHSTP Station Area Parking Guidance document for ridership forecasts. Sizing of the public Concourse and related facilities shall consider the appropriate peak period within the daily peak as specified and detailed in Section 14.3.1.5. Public spaces include Concourse paid and Free Areas, passageways, and vertical circulation elements.

Non-public Areas – Non-public station areas comprise the majority of Concourse space and are generally unaffected by forecast ridership; space required for these uses is determined by operational and technical needs. Non-public areas include passenger services, operations, Core Systems rooms, plant rooms, and terminal facilities where they occur.

Terminals – Terminal stations shall be planned in accordance with the goals, facilities, and functional needs of Intermediate Stations while also providing space to accommodate terminal functions. Specific terminal space requirements are described in Section 14.3.6.5 and throughout this document. Additional platforms may be required to accommodate terminal train operation needs. The special operational conditions of terminals will generally result in a larger station than the intermediate type.

Station Sites – Site conditions will influence station planning and size. Each individual site will influence placement and number of exterior entrances and organization of interior spaces. Placement of intermodal transportation connections will depend on availability of adjacent site

area and optimum placement in relation to entrances. Where site conditions and passenger use warrant entrances on two sides of the trackway, dual entrances may be considered.

C. Passenger Movement

Passenger movement through primary public activity zones is as follows:

- Passengers enter through a station entrance and into the Concourse where information, ticketing, waiting, and basic services are easily identified and located.
- Departing passengers may either proceed to a waiting area or patronize station amenities within the Concourse.
- Ticketed passengers may proceed through Fare Gates into the Paid Area-waiting zone.
- Before the train's departure time, passengers will be instructed by public address (PA) and dynamic signage to proceed to the appropriate platform to await boarding the train.
- When the train arrives, waiting passengers board after the arriving passengers alight.
- The sequence is reversed for arriving passengers.

D. Level of Service

The primary performance measure used to determine adequacy of pedestrian circulation spaces within the station shall be Level of Service (LOS), as defined by Fruin,[1] which qualitatively and quantitatively describes the permissible degree of pedestrian congestion, based on density and walking speed at key passenger circulation locations within the station. Stations shall be planned according to LOS B for the peak design year unless noted otherwise.

E. Station Vertical Configuration

Stations are identified according to vertical platform location, as follows:

Elevated Stations – Platforms are supported on a superstructure above grade or passing over surface features.

- **At-grade Station –** Platforms are located at ground level.
- **Underground Stations –** Platforms are located below grade.

F. Station Vertical Organization

The two primary station levels are Platform and Concourse. These areas are typically situated on different levels but may be at the same level.

Platform – Provides waiting and circulation space adjacent to the trainway.

Concourse – Situated between platforms and the entrances/exits and provides space for waiting, fare collection, passenger circulation, station amenities, support and plant space.

[1] *Pedestrian Planning and Design*. John J Fruin, Ph.D. 1987.

Mezzanine – In some cases, may be planned as an intermediate level between the Concourse and Platform levels.

G. Station Platform Configuration

Station platforms shall be configured using either a Side or a Center Platform, depending on numerous interdisciplinary design and operational considerations. Most Intermediate Stations will be configured with Side Platforms.

Side Platform – A single track is positioned adjacent to each platform. Platform vertical circulation, amenities, and staff spaces may be duplicated at each platform. Side platforms are preferable where both through tracks and stopping tracks serve the station.

Center Platform – Tracks run alongside both sides of a single platform. Passengers utilize the same vertical circulation elements to access either northbound or southbound trains.

H. Emergency Access

In accordance with NFPA 130, local emergency authorities shall respond to a station emergency according to a pre-approved emergency plan. Emergencies may include a fire within the station public or non-public areas, a train collision or derailment, loss of station or traction power, necessity to evacuate passengers, disabled or stalled train at a platform, natural disaster, presence of hazardous materials, passenger need for first aid, earthquake, or other emergency.

In the event of an emergency, the local first-responder shall be summoned and shall require access into all areas in and around the station. At least one entrance shall be designated as the emergency entrance. Station design shall incorporate provisions as required by the State fire marshal and local fire jurisdiction to allow firefighter access to any and all portions of the station (i.e., dedicated firefighters' entrances, stairs or other). Station plans shall demonstrate acceptable strategies for emergency access as well as emergency evacuation.

14.3.1.5 Passenger Accommodation

A. Public Areas

Public station areas intended for passenger circulation shall accommodate forecast ridership for the Full Build (2035) or projected Phase I, whichever is higher under estimated peak period and emergency conditions. Refer to the CHSTP Station Area Parking Guidance document for ridership forecasts.

Peak-period ridership is determined using the ridership parameters in the following sections.

B. Boardings

Boardings are indicated using a subscript "B" (P_B).

Daily Boardings – Design shall be based on the peak day boardings (as provided in a separate document).

Peak Hour Boardings (P_{60B}) – Ridership peaking factors to convert peak daily boardings to peak-hour boardings are provided in Technical Memo 4.2 Phase 1 Service Plan.

Peak 30-minute Boardings (P_{30B}) – One-half of all the peak-hour boardings, multiplied by a system surge factor of 1.2.

Peak 15-minute Boardings (P_{15B}) – One-quarter of the peak-hour boardings, multiplied by a system surge factor of 1.3**.**

Peak minute Boardings (P1B) – Peak-hour boardings divided by 60 and multiplied by a system surge factor of 1.5.

Table 14-1: Peak Period Boardings

Symbol	Description	Formula
P_{60B}	Peak Hour Boardings	Peak day boardings x Peaking Factor
P_{30B}	Peak 30-minute Boardings	$(P_{60B} \div 2) \times 1.2$
P_{15B}	Peak 15-minute Boardings	$(P_{60B} \div 4) \times 1.3$
P_{1B}	Peak Minute Boardings	$(P_{60B} \div 60) \times 1.5$

C. Alightings

Alightings are indicated using a subscript “A” (P_A).

Peak alightings (P_{60A}, P_{30A}, P_{15A}, P_{1A}) – Assumed to be equal to peak boardings.

D. Other Station Users

It is expected that some passengers will be dropped off or picked up at the station. The number of people who drop-off or meet HST passengers is estimated to be one-tenth of the total peak boardings and alightings. These users shall be added to boardings and alightings where appropriate to provide adequate space they may occupy. Total station occupancy also includes station staff, which varies based on operating conditions and station type.

E. Maximum Train Load

Certain station facility requirements will be based on estimated maximum passenger occupants in a trainset. High-speed train sets shall accommodate between 900 and 1,000 seated passengers; therefore, the maximum number of alighting passengers shall be 1,000 per train.

F. Delayed Trains

Station facilities shall be able to accommodate the additional passengers that will accumulate within the station when a train is cancelled or seriously delayed.

14.3.2 Platforms

The primary function of station platforms is passenger boarding and alighting.

14.3.2.1 Platform Geometry

A. Length

The usable length of a platform along which a HST will stop shall be:

- *Desirable* – 1,410 feet
- *Minimum* – 1,370 feet

In order to allow for potential future platform extension, potential for adding tangent track beyond the platform shall be considered.

B. Platform Width

Platform width shall meet the requirements of NFPA 130 and ADA. The platform width shall be sufficient to allow accessibility and circulation for the maximum number of passengers based on projected ridership for the station.

- Center platform:
  - *Minimum* – 30.0 feet
  - *Exceptional* – 25.0 feet
- Side platform:
  - *Minimum* – 20.0 feet
  - *Exceptional* – 18.0 feet

Module – Platform width shall be a multiple of the 12-inch floor module in order to minimize cutting of floor-tile finish materials where they occur.

Tapering – Where platform end tapering is provided, the taper should be 10 feet long and gradually increase the distance from the platform edge to centerline of track by 0.5 foot. Taper shall be located outside the areas of trainset doors used by the public. Taper shall be located beyond the minimum station platform length.

C. Platform Cross Slope and Drainage

Platforms shall slope away from the platform edge to provide for separation of platform drainage from track drainage as well as for safety. Drains along the toe of platform slope shall be provided.

- Minimum – 1.0%
- Maximum/Exceptional – 2.1%

D. Platform Longitudinal Slope

Platform longitudinal slope shall follow the longitudinal profile of the rail. It is desirable for station tracks to be level. Where track slope at platforms is unavoidable, slope shall not exceed 0.25 percent.

E. Platform Curvature

Platforms shall be on a tangent alignment along the usable length. If a horizontal curve is unavoidable, the curve shall be the largest possible radius and shall require a design variance. Spirals and superelevation within platform limits shall be avoided.

F. Platform Height Above Rail

Station platforms shall be designed to provide level boarding. Although rolling stock has not yet been selected, the floor height of trainsets under consideration ranges from 45.5 inches to 51.2 inches above the top of rail. When the rolling stock is selected, the platform height above top of rail shall be set to the same as the nominal car floor height at the doors of the vehicle.

The vertical dimension between the train door threshold and the platform edge is as follows:

- Desirable – 0 inches
- Maximum – ± 5/8 inches

G. Platform Edge to Track Centerline

The horizontal dimension between the centerline of track and the platform edge shall be one-half the width of vehicle + 2.75 inches. This allows for a plus or minus construction tolerance of 0.25 inch in regard to the 3-inch maximum gap between platform edge and train door threshold allowed by ADA, measured when the vehicle is at rest.

Refer to the *Trackway Clearances* chapter for the nominal distance between track centerline and platform edge.

H. Platform Obstructions

Platform obstructions lower than 8 feet–0 inches above floor level such as columns, walls, stairs, sign posts, shall be set back from the platform edge to allow for safe and efficient platform circulation. Minimum setbacks from platform edge are indicated in Table 14-2.

Table 14-2: Platform Obstructions

Element Length	Minimum Dimension from Platform Edge*	Exceptional Dimension from Platform Edge*
Short Obstruction (less than 3'-4")	7'-0"	6'-2"
Long Obstruction (more than 3'-4" [1])	9'-0"	8'-0"

[1] Two small point obstructions separated by less than 8 feet-0 inches shall be considered a long obstruction.
* Dimensions are measured parallel to tracks.

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Sightlines for train operators, station operators and patrons waiting on the platform shall not be hindered by canopies, signage, or other potential aerial obstructions.

Columns – Columns running the length of the platform shall be limited in size and in quantity in order to avoid the effect of a wall. Columns shall be located to avoid obstructing train doors.

Overhead Contact System Poles – Poles supporting the Overhead Contact System (OCS) shall not be located on station platforms.

I. Under-platform Refuge Area

A refuge space under the platform edge shall be provided at track level, a minimum of 2 feet-6 inches high and 2 feet-6 inches deep along the entire length of the platform. The refuge space shall be open at platform ends to allow egress. High access panels (2 feet-6 inches wide and 2 feet-6 inches) shall be provided at maximum 300 feet on center along the length of the refuge area.

J. Clearance to Metal Objects

Metal objects on platforms shall be a minimum distance from the platform edge of 8 feet. Any metallic object closer than 8 feet from the platform edge shall be grounded to the platform counterpoise.

14.3.2.2 Platform Planning

A. Passenger Capacity

Width – Platform width shall accommodate the predicted volumes of passengers boarding and alighting from trains during normal and irregular operation. Width shall be either the minimum width indicated in the previous section or the width required to accommodate the Platform Occupant Load, whichever is larger.

Occupant Load – Adequate platform capacity shall be confirmed by first calculating the maximum Platform Occupant Load (POL). The POL is the maximum number of passengers who will gather on the platform during the interval immediately following the departure of one train and the arrival of the next during the peak hour.

Irregular Operation – During normal operation, passengers will alight from a train in accordance with estimated peak-hour flow. However, there may be causes (mechanical or operational) for all passengers traveling in a fully loaded train to disembark at any station. These passengers may be required to detrain onto a platform already occupied by peak-hour passengers waiting to board.

At Intermediate Stations, maximum POL during irregular operation therefore is calculated as one fully loaded train per platform edge plus the boarding load in peak or non-peak direction.

At Terminal Stations, maximum POL during irregular operation is calculated as one full train plus boarding load in peak direction.

Emergency Evacuation – The irregular operation scenario is the basis for emergency evacuation of the POL.

Minimum Platform Area – The platform shall be sized to accommodate the POL, allowing 25 square feet per boarding passenger for passengers to circulate and wait during the peak period (pedestrian walkway LOS B). Upon train arrival, the addition of alighting passengers on the platform may result in a temporary LOS C for a short duration. Minimum platform area shall be exclusive of the 2-foot-0-inch safety edge strip, and platform obstructions such as escalators, stairs, columns, or other fixed elements.

B. Platform Edge

Floor Finish – Platform edge design and materials shall be standardized throughout the HST System. A standard 24-inch-wide clear zone of tactile floor tile shall be provided in accordance with state and federal regulations along the entire length of each platform edge. Adjacent to this edge strip and adjacent to selected vehicle doors a continuous 12-inch-wide zone of tiles shall be provided in a contrasting color. Platform edge provisions shall be confirmed with current accessibility requirements.

Lighting – Continuous overhead lighting shall be provided along the platform edge.

C. Platform Ends

Platform ends shall be delineated by railings and security gates at elevated and at-grade platforms, or end walls and gates at underground stations. Platform end gates shall be alarmed and appropriate signage applied to discourage unauthorized entry to the trackway or walkways. Stairs shall be provided as needed between platform and walkways.

D. Protection Screens

Provision shall be made for the installation of protection screens between through-tracks and station platform tracks. Screen height shall be approximately 6 feet-0 inches above platform finish floor. Screens shall provide acoustical baffles as well as space for potential advertising panels. Transparent sections to permit cross-platform views are desirable. OCS poles shall be integrated into the screen configuration where appropriate.

E. Platform Ancillary Spaces

Ancillary spaces for Core Systems, operations, storage, and maintenance functions shall be necessary on, adjacent to, or beyond public-platform areas. These spaces shall be located where circulation flow and sight lines shall not be obstructed. Terminal station platforms shall be provided with operations and maintenance facilities including a Platform Agent Booth (where operationally appropriate), and cleaning and storage rooms at selected stations. Underground and Terminal Stations may require additional special platform ancillary spaces.

Under-platform space (excluding the refuge area) may be used to run cables and other mechanical and electrical systems. Sections shall be divided with appropriate fire separations.

F. Weather Protection

Canopies – Canopies shall be provided along the entire length of the platforms and extend transversely from the outer wall of each platform to at least 12 inches beyond the edge of platform. Coordinate canopies with the OCS.

Wind Screens – Wind screens may be used if local wind conditions justify passenger protection. Wind screens shall be glazed to ensure visibility and detailed with consideration for regular maintenance needs.

Clear-glazed enclosures with seating are an acceptable alternative to continuous platform screening; however, windscreen enclosures shall not obstruct views or circulation.

G. Vertical Circulation

Wherever possible, access to platforms from the Concourse or Mezzanine will be arranged to encourage distribution and collection of passengers along the entire platform length.

H. Concealed Spaces

Corners, recessed areas, and other potential hiding places shall be minimized.

I. Platform Amenities

Refer to Section 14.3.8 for furnishings, fixtures and equipment to be provided on platforms.

J. Grounding and Bonding

For grounding and bonding requirements on platforms, refer to the *Grounding and Bonding Requirements* chapter.

14.3.2.3 Special Platform Conditions

A. Platforms in Shared Use Corridors

At stations where HSTs and conventional passenger trains are expected to stop, platform design shall accommodate both high-speed and regional rail platform requirements. Specific compatibility issues related to platform length, height, clearances and door location markers shall be considered. Dedicated platforms which serve each type of service are preferred.

B. Platforms Adjacent to Through Tracks

The speed of trains on tracks adjacent to station platforms shall not exceed 125 mph. At stations accommodating through-trains operating on tracks adjacent to the platform, platforms shall be marked to indicate locations for passengers to wait. Passengers shall wait 5 feet-0 inches (minimum) from the platform edge. Where this zone is marked, 3.0 feet shall be added to the setback from platform edge to large obstructions so that minimum setback is 12 feet-0 inches.

C. Train Stopping Position

It is assumed that both single (200 m) and coupled (400 m) trainsets shall be operated from commencement of system operation. Platform finishes, equipment and signage shall therefore reflect the use of both shorter and longer train lengths.

14.3.3 Concourse and Mezzanine

The Concourse is the interior space between station entrances and platforms, including the free and Paid Areas. The Concourse is the gateway to the rail service and provides passengers with information, ticketing, and waiting areas for passengers and "meeters and greeters."

Where height is available, a mezzanine level may provide an intermediate space where some of these passenger and staff facilities are located. This section addresses Concourse public areas. Non-public Concourse areas are addressed elsewhere in this chapter.

14.3.3.1 Concourse Planning Standards

Openness – The Concourse shall be open, spacious and have a high level of visibility to optimize passenger orientation and staff surveillance.

Obstructions – Passenger facilities such as public toilets, ticketing windows, information kiosks, and all associated queues shall be located clear of primary paths of pedestrian movement. Primary pedestrian circulation areas shall be free of columns and other obstructions.

Ceiling Height – Suspended Concourse ceilings shall be no less than 10 feet above the finished floor; a minimum of 16 feet is preferred. Clearance beneath signs or other obstacles shall be no less than 8 feet-0 inches. A ceiling utility zone no less than 3 feet-0 inches clear height shall be provided between suspended ceilings and the structure above.

Concourse Slope and Drainage – Floor drains in Concourses shall be provided. However, Concourse floors need not slope to drains except where weather protection cannot prevent wind-blown rain from entering the station.

14.3.3.2 Entrances

General – Entrances provide a gateway between the station building, the station site, and the surrounding community. As such, they shall be distinctively designed, clearly identifiable from either the station interior or exterior, and easily accessible. Entrances may be freestanding or integrated into surrounding developments provided they are clearly identifiable as station entrances. For stations with more than one major entrance, one entrance shall be designated as the main entrance and be provided with all required passenger facilities. Other entrances may be provided with minor amenities and ticketing provisions. A free passageway shall connect secondary entrances to the primary entrance.

Location – Locate entrances wherever passengers may need to connect with other modes of transportation, e.g., adjacent to taxi and bus connections, kiss and ride, passenger parking, etc.

Number – Stations shall have at least two entrances. Entrances shall also function as emergency exits that meet exit requirements. Entrances may be supplemented with emergency exit-only doors as required to provide the required exiting capacity.

Size – The minimum width of each entrance shall be 10 feet-0 inches. At least one entrance shall have a width of 15 feet-0 inches. Floors directly adjacent to entrances shall be level for at least 10 feet-0 inches inside and outside of the entrance.

Doors – Automated sliding or swinging doors, 3 feet-0 inches minimum width per leaf, shall be provided. A minimum clear space of 2 feet-0 inches shall be provided to each side of a door or group of doors. Each entrance shall have a minimum width of one-half of the required egress width for the station.

Other Considerations – Entrances shall be ADA and universally accessible. Exterior entrances shall provide wind, rain, and, if appropriate, flood protection. Vestibules will be considered where station temperatures will be dramatically different from exterior temperatures. Every entrance shall be provided with a rolling shutter or security gate to allow for station closure.

14.3.3.3 Free Area

General – The Concourse Free Area provides space for patrons to circulate freely without a ticket and where space is provided for station entrances, passenger circulation, public restrooms, passenger information, and ticketing. Intermediate stations will preferably provide a single Free Area in order to consolidate passenger amenities and staff functions within a single managed space. It shall be located on the ground level adjacent to the entrances to facilitate passenger orientation upon entering the station. The space shall immediately convey the dynamic image and identity of an HST station.

Multiple Free Areas – At Terminal Stations and special Intermediate Stations where station access conditions necessitate separation of entrances and multiple Free Areas, free pedestrian walkways shall connect the Concourse Free Areas. At stations with intermodal transfers, the locations of other modes may make this infeasible and duplication of passenger ticketing and information services may be necessary.

Non-HST Patron Circulation – Depending upon the station site configuration, the station may be used for circulation through the site or neighborhood. Where appropriate, the station Free Area will allow for circulation through the station and across station area tracks. This will enhance the importance of the free public space and integration of the station into station area development. Where pedestrian circulation is provided through the station, provisions shall be made for secure closure of the station after operating hours.

A. Free Area Circulation

General – The Concourse Free Area contains circulation space for passengers traveling between station entrances and the Paid Area. Primary routes of passenger movement within the Free Area shall connect all primary entrances with one another without obstruction. Ticket sales, passenger information, public toilets, and waiting areas shall be located adjacent to primary circulation paths and shall be clearly visible to passengers. Passenger information within the Free Area shall include system signage, passenger information system displays (including a prominent timetable screen displaying train arrivals and departures), and a large-scale clock.

Location – Concourse circulation will typically be located on the ground level adjacent to entrances for clarity of function for passengers entering the station.

Configuration – Wherever practical, turn-backs and U-turns shall be avoided since passengers circulate between entrances, ticketing facilities, and the Fare Collection Line. Cross flows shall be avoided between boarding and alighting passengers. Configuration shall allow for passenger circulation between HST and other rail or transit systems.

Sizing – Adequate width shall be provided for unobstructed horizontal circulation between entrances and the Concourse Paid Area. Circulation width is based on peak-hour passenger boardings and alightings. Net Free Area circulation width (C_f), exclusive of any obstructions, is calculated as shown in Table 14-3.

This circulation width shall be exclusive of other required spaces such as waiting areas, information kiosks, or queues for ticket purchases. Where the primary circulation route bifurcates towards multiple exits, the minimum width may be proportionate to the estimated number of entrance users.

B. Free Waiting Areas

General – Free waiting areas provide places for passengers and the general public to wait prior to entering the Paid Area or leaving the station.

Location – Waiting areas shall be located so they are easily accessible but do not impede the principal circulation paths between entrances and the Paid Area. As some of this space is dedicated for "meeting and greeting" of passengers, waiting areas shall be located adjacent to primary circulation paths. Spaces shall be organized so that those waiting do not impede flows for others going to and from the platforms. There may be single or multiple waiting areas within the Free Area. Queues for ticketing facilities may not encroach into waiting areas.

Amenities – Seating and provisions for visual display and audio announcement of train arrival and departure information shall be provided in waiting areas. Waiting areas shall include power outlets for laptops, Wi-Fi, and television monitors.

Sizing – Total area for waiting within the Free Area (W_f) shall be sized as shown in Table 14-3.

C. Ticketing and Station Information

General – Ticketing and station information provisions are located within the Concourse Free Area and shall be directly visible to passengers entering the station.

Ticketing – Space shall be provided within the Free Area for a Ticket Sales Office and ticket vending machines (TVMs). Queuing areas for ticketing functions shall not encroach into other required Free Area spaces. Space requirements and standards are discussed in Section 14.3.6.1. Fare collection is addressed in Section 14.3.3.5.

Station Information – A Passenger Information Counter shall be provided within the Free Area as described elsewhere in this chapter. This counter and its queue shall be located adjacent to

the primary circulation routes and shall not obstruct primary passenger circulation. Other unstaffed information kiosks providing written information, maps, train schedules, etc., shall be located within waiting areas and near entrances.

14.3.3.4 Paid Area

Defined – The Concourse Paid Area is located between the Fare Collection Line and the platforms. It includes Concourse circulation space, waiting areas, paid public restrooms (at Terminal Stations only), mezzanine (where occurs) and vertical circulation elements leading to platforms. Vertical circulation to platforms shall be clearly visible from the Fare Collection Line, permitting passengers to access any platform. Platforms are located within the Paid Area but are addressed separately in Section 14.3.2.

Access – Access into the Paid Area requires a paid fare and possession of a valid ticket.

Demarcation – The demarcation between Free Area and Paid Area is located at the Fare Collection Line, which employs mechanical Fare Gates and a Passenger Service Booth (PSB).

Security Provisions – Space for security equipment and staff shall be provided as defined in Section 14.3.11.

Passenger Information – Extensive directional signage and passenger information shall be displayed throughout the Paid Area.

A. Paid Area Circulation

General – Direct movement between the Fare Collection Line and platforms shall be facilitated through clear sight lines and logical configuration. Access to the platform may require vertical circulation including stairs, escalators, and elevators (vertical circulation is described in Section 14.3.4.3). Waiting areas shall be located within the Concourse Paid Area and shall not impede major circulation routes. Avoid turn-backs wherever practical, providing direct routes between the fare line and vertical circulation.

Sizing – Adequate width shall be provided for unobstructed horizontal circulation between the Fare Collection Line and vertical circulation leading to platforms. Circulation width is based on peak-hour passenger boardings and alightings. Net Paid Area circulation width (C_P), exclusive of any obstructions or other required spaces such as waiting areas, is calculated as shown in Table 14-3.

B. Paid Waiting Areas

General – Paid waiting areas provide a place for passengers to wait prior to entering a platform. Short-term seating, information screens, and waste receptacles are located in this area.

Location – Waiting areas shall be located so they are easily accessible but do not impede the principal circulation paths between the Fare Collection Line and vertical circulation leading to platforms. Spaces shall be organized so that those waiting do not impede circulation of others going to and from the platforms. There may be single or multiple waiting areas within the

Concourse Paid Area. Additional waiting areas may be provided on platforms but shall not impede platform circulation.

Amenities – Seating and provisions for visual display and audio announcement of train arrival and departure information shall be provided in waiting areas. Waiting areas shall include power outlets for laptops, Wi-Fi, and television monitors. Public wireless services shall be coordinated with the station communication system. Views between Concourse and platforms shall be provided wherever possible.

Sizing – Total area for waiting within the Paid Area (W_p) shall be sized as shown in Table 14-3.

Table 14-3: Concourse Circulation and Waiting Area

Symbol	Description	Formula [1, 2]
C_f	Net Free Area circulation width	$(P_{15B} + P_{15A}) \div (15 \times 10$ people/ft/min)
C_p	Net Paid Area circulation width	$(P_{15B} + P_{15A}) \div (15 \times 10$ people/ft/min)
W_f	Net waiting area in Free Area	$[(P_{15B} \times 1.1) + (P_{15A} \times 0.1)] \times 14$ square feet
W_p	Net waiting area in Paid Area	$P_{15B} \times 14$ square feet

(1) P_{15B} = Peak 15 minute boardings; P_{15A} = Peak 15 minute alightings;
(2) at LOS B

C. Premium Club Lounge

General – Full build-out Terminal Stations shall incorporate into the Concourse Paid Area a Premium Club Lounge for business travelers and "frequent rider" customers. The facility shall provide premium amenities, including computers, printers, internet, conference room, ticketing, light snacks and beverages, passenger services, and concierge services. Dedicated restrooms may be provided for customers.

Location – The Premium Club Lounge shall be located within the Concourse Paid Area, close to the entrance to the platforms, and will preferably provide natural light. This facility may be operated on a subscription basis as a for-profit enterprise, an amenity included with certain classes of tickets, and/or with frequent traveler status as a prerequisite.

Designated Stations – Terminal Stations, including San Francisco Transbay, Sacramento, Los Angeles, Anaheim and San Diego.

Size – 600 square feet, minimum

14.3.3.5 Fare Collection

A. Elements of Fare Collection

Stations shall be designed to allow for the use of Fare Gates. Provisions for fare collection in the station shall include the following:

- Ticket Sales Office
- Ticket vending machines
- Fare gates

It is assumed that 80 percent of all peak-hour passengers will purchase tickets at the station. The remaining 20 percent of peak-hour passengers will purchase tickets via other means prior to arriving at the station. Detailed information regarding fare collection policies and required equipment are addressed in a separate operations document.

B. Ticket Sales Office

General – It is assumed that 15 percent of all peak-hour passengers will purchase tickets at the Ticket Sales Office from station staff in lieu of the TVMs. Other ticketing transactions may also be conducted, including refunds, ticket adjustments, or retrieval of reserved tickets.

Location – One secure Ticket Sales Office shall be provided at the primary Concourse Free Area between the public and non-public areas and shall be readily visible from station entrances. In the event that a station provides more than one Concourse Free Area, a second Ticket Sales Office may be required only if warranted by substantial patronage and acceptable within HST operations policies. Access shall be via a secure corridor, through a security door with viewing panel.

Window Quantity – Ticket windows shall be calculated as shown in Table 14-4, rounded up to the nearest whole number. A spare window may be included to accommodate ticket staff shift changes. At least one ticket window shall be universally accessible to all passengers.

Ticket Office Size – Each window shall be minimum 5 feet-0 inches wide. A minimum of 75 square feet of ticket office area shall be provided for each window. Refer to Section 14.3.4 for queuing distance at windows.

Related Provisions – Ticket sales administrative offices and other ticketing-related offices shall be located adjacent to the Ticket Sales Office within the non-public area.

C. Ticket Vending Machines

General – It is assumed that 65 percent of peak-hour passengers will obtain their tickets at TVMs within the stations, either by purchasing tickets or printing pre-purchased tickets.

Location – TVMs shall be located in the Concourse Free Area near the Ticket Sales Office and adjacent to the main circulation routes. The machines and corresponding queuing space (summarized in Section 14.3.4) shall not encroach into the passenger circulation space. TVMs shall be located against a wall, in view of entrances. For stations with multiple entrances, it may be appropriate to locate TVMs at secondary entrances in order to ensure logical passenger flow. TVMs shall be grouped into clusters. Depending on the size of the station and the number of TVMs, multiple clusters may be appropriate.

TVM Quantity – TVMs shall be provided to meet peak passenger demand per Table 14-4, rounded up to the nearest whole number. One additional TVM shall be provided for out-of-service conditions.

TVM Size – For space planning purposes, TVMs can be assumed to be 3 feet-4 inches wide, 3 feet-0 inches deep and 6 feet-0 inches high, and spaced at 4 feet-0 inches on center. TVMs shall fit into the standard station module. Space shall be allowed for addition of a minimum of 10 percent more TVMs if passenger demand requires additional machines.

Table 14-4: Ticket Sales Facilities

Element	Station Quantity	Station Minimum
Ticket Windows	$P60_B \div 600$	2
Ticket Vending Machines	$P60_B \div 280$	3

D. Fare Gates

General – Fare Gates shall demarcate the separation between Free and Paid Areas. Standard gates shall accommodate most passengers while oversized gates shall be available for people with luggage and persons with special accessibility needs. A PSB (Section 14.3.8.2) shall be located adjacent to the main array of gates to assist passengers with operation of Fare Gates.

Size – Standard width Fare Gates are approximately 2 feet-0 inches clear opening and spaced 3 feet-0 inches on center. Oversized gates are 3 feet-0 inches clear opening and spaced 4 feet-0 inches on center. Provisions shall be made for underfloor power and data conduits.

Quantity – The number of Fare Gates provided for arriving and departing passengers is based on peak ridership and 50 people per minute (ppm) capacity for fully open gates per Table 14-5.

Table 14-5: Fare Gates

Station Type	Travel Direction	Quantity Formula [1,2]
Terminal	Arriving Gates	(Train Capacity / headway in minutes) / 50 ppm Fare Gate capacity
Terminal	Departing Gates	(P_{15B} / 15) / 50 ppm Fare Gate capacity
Intermediate	Arriving Gates	(1.125 x P_{1A}) / 50 ppm Fare Gate capacity
Intermediate	Departing Gates	P_{1B} / 50 ppm Fare Gate capacity

[1] P_{15B} = Peak 15 minute boardings; P_{15A} = Peak 15 minute alightings
[2] P_{1B} = Peak minute boardings; P_{1A} = Peak minute alightings

Additional Gates – The number of gates shall be rounded to the next highest integer. One additional gate shall be provided if the number of required gates is less than 10. Two additional

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gates shall be provided if the number of required gates is equal to or greater than 10. Where practical, expansion capacity for additional future Fare Gates may be provided.

Oversized Gates – At each Fare Gate array, at least one Fare Gate shall be oversized. More may be necessary for stations serving more passengers with luggage or as required by ADA.

Emergency Gates – At least 2 emergency and/or service gates shall be provided along the free/paid line to be used by staff and in case of emergency. More gates may be warranted for emergency evacuation.

Queuing – Refer to Section 14.3.4 for queuing distances required at Fare Gates.

Operation – Under emergency situations, Fare Gates shall remain in the open position.

Provision for Security Measures – An allowance for potential security facilities shall be provided. This space shall be located on the Free Area side of each gate array. The size of this space shall be 20 feet deep by the total width of the Fare Gates.

14.3.3.6 Public Restrooms

Locations – Intermediate Stations shall provide public restrooms only within the Concourse Free Area.

Terminal Stations shall provide public men’s and women’s restrooms within both the Concourse Free Area and the Concourse Paid Area. Additionally, two unisex restrooms shall be provided within the Paid Area for mobility and special needs passengers.

Public restrooms shall be located adjacent to main circulation routes. Restroom entries shall be clearly visible from circulation routes.

Size – Restroom facilities shall be based on projected occupant loads. The minimum occupant load for the facility will be based on 15-minute peak station patrons (P_{15}) and applicable code requirements.

Access – Paid area restroom entrances shall be screened vestibules in lieu of doors. Free area restroom entrances shall be provided with lockable doors. Access to Free Area restrooms will be controlled by station staff.

Provisions – Toilet stalls shall be oversized (minimum 3 feet-0 inches wide x 6 feet-0 inches deep) to accommodate passengers with luggage. Partitions shall be ceiling-mounted. Surfaces and fixtures shall be vandal resistant. Washable surfaces and floor drains are required. Accessories shall include hands-free air dryers, soap dispensers, paper towel dispensers, toilet paper dispensers, framed mirrors, and foldable baby changing tables in both men’s and women’s restrooms.

A janitor’s room shall be provided adjacent to every set of public restrooms.

14.3.3.7 Passenger Amenity (Commercial) Spaces

Size – It is likely that passenger amenity spaces will be provided at stations for commercial passenger services. In order to not preclude addition or inclusion of these spaces, a standard assumption for passenger amenity space can be used as shown in Table 14-6.

Table 14-6: Passenger Amenity Space Allocation

2035 Daily Boardings	Passenger Amenity Space
Less than 5,000	3,000 square feet
5,000-10,000	6,000 square feet
More than 15,000	9,000 square feet

Location – Where passenger amenity space is provided in the Free or Paid Area, it shall be located close to major passenger circulation routes or waiting areas but shall not impede passenger flow.

Services – Routes to supply passenger amenity spaces shall be separated from passenger circulation routes.

14.3.4 Passenger Circulation

14.3.4.1 Circulation Planning

Effective station planning provides passengers with clear circulation patterns, as consistent as possible from station to station, so that passengers are able to safely and comfortably circulate throughout the HST System. Station circulation spaces include platforms, mezzanines, Concourses, bridges, pedestrian walkways, elevators, escalators, stairs, ramps, and emergency routes. Access and circulation shall be simple, obvious, and comfortable, recognizing many passengers will be unfamiliar with traveling on a high-speed rail system.

A. <u>Basis for Sizing</u>

Generally, public spaces provided for passenger circulation shall be sized to accommodate peak-period ridership for Fruin LOS B during normal station operations. Where space is constrained by physical conditions that cannot be mitigated cost-effectively, facilities may be designed for a peak LOS C as approved by the Authority.

Stations shall provide evacuation capacity in accordance with NFPA 130 and as described in Section 14.3.5.

B. <u>Circulation Principles</u>

Circulation patterns shall consider the following principles:

- **Right-hand Rule –** Observe right hand flow for pedestrian circulation.
- **Cross Flows –** Avoid passenger cross flows wherever possible.
- **Dead Ends –** Avoid dead end conditions wherever possible.

- **Obstructions –** Columns, queues, kiosks, equipment, etc., shall not encroach into circulation routes.
- **Directional Travel –** Circulation routes and station layouts shall minimize changes in direction.
- **Visual Orientation –** Circulation routes and station layouts shall facilitate passenger orientation by means of placing each sequential stage of circulation (ticket gates, escalator, platform, etc.) in clear view of the current stage.
- **Decision Points –** Where there is a need to make a directional decision, the necessity for passengers to make multiple decisions at a single location shall be avoided.
- **Safety –** Concealed corners or recesses, which may be used as hiding places, shall be avoided. Passengers' perceptions of safety are a fundamental system requirement.

C. Queuing Space

Space for passengers to queue at circulation elements shall be provided (per Table 14-7). This space shall not overlap or encroach into primary circulation routes. Because escalators will be reversible, unobstructed queuing space shall be allocated at the top and bottom of every escalator.

Table 14-7: Queuing Distance Requirements

Element	Dimension (min.)
Escalator (top and bottom from working points)	15 feet 0 inches
Stair (top and bottom from first tread)	15 feet 0 inches
Elevator Entrance	8 feet 0 inches
Ticket Gates, both free and paid sides	20 feet 0 inches
Ticket Sales Windows	20 feet 0 inches
Ticket Vending Machines	8 feet 0 inches
PSB	10 feet 0 inches

14.3.4.2 Horizontal Circulation

Adequate horizontal circulation width is essential to achieve the general circulation planning principles listed in the preceding section. Horizontal circulation width provisions are based upon accommodating the flow of a given number of passengers during the peak minute, occupying a given width, and walking at a given average speed.

A. Passageways

Calculated Width – Minimum net width of any passageway shall be calculated on the basis of the sum of the peak 15-minute boarding and alighting passenger flows.

Passageway width may be calculated based upon LOS B horizontal circulation unit capacity (10 people per foot per minute) during peak-minute surges as shown in Table 14-8.

Table 14-8: Passageway Width Calculation

Symbol	Description	Formula [1, 2, 3]
P_u	Unconstrained Passageway width	$(P15_B + P15_A) \div (15 \times 10$ p/ft/m$)$
P_c	Constrained Passageway width	$P_u + B$

(1) P_{15B} = Peak 15 minute boardings; P_{15A} = Peak 15 minute alightings
(2) at LOS B,
(3) B = Buffer Zone – 1'-6 inches for space adjacent to each wall, barrier or railing, 2 feet-0 inches at platform edge except in cases when the train remains at the platform edge such as during emergency train evacuation

Minimum Width – The greater of the calculated passageway width and minimum passageway widths shall be provided (as shown in Table 14-9).

Table 14-9: Passageway Width Minimums

Element	Dimension
Public areas	16 feet 0 inches preferred minimum
Public areas with unidirectional movement	6 feet 0 inches absolute minimum
Public areas with bidirectional movement	8 feet 0 inches absolute minimum

Equivalent Capacity – Passageways shall have a capacity at least equal to the capacity of any stairs and escalators that feed it. Passageways leading directly to/from platforms shall be sized to accommodate potential 50 percent surge loadings of boarding and/or alighting passengers.

Constraints – Horizontal circulation may be constrained by walls, barriers, or platform edges as in a passageway, pedestrian bridge, platform or corridor, or may be unconstrained as in an open Concourse or mezzanine. Where passageways are constrained, extra width shall be added to allow a "buffer zone" (indicated in Table 14-8), which is a distance from which people tend to stay away from vertical surfaces when walking.

B. Pedestrian Bridges and Tunnels

Minimum width of pedestrian bridges and underground tunnels shall be calculated in the same way as described in the previous Passageways section. Natural light shall be introduced into bridges, where practical.

C. Height

Minimum horizontal circulation ceiling height shall be 10 feet-0 inches above the finished floor. Suspended signs, fixtures, or fittings shall have a vertical clearance of at least 8 feet-0 inches above the finished floor or as required to conform to accessibility standards.

D. Floor Slope

Floors of horizontal circulation elements shall not exceed a 5 percent slope.

E. Moving Pedestrian Walkways

Where continuous horizontal Concourse or passageway circulation distances exceed 600 feet, the use of moving pedestrian walkways may be considered.

F. Non-public Corridors

At non-public spaces, corridor width connecting service and plant rooms shall be no less than 3 feet-8 inches clear width or as determined by building code. Corridor width shall consider access needs for installing or replacing equipment.

Wherever possible, non-public circulation routes for station staff, supplies, and refuse collection shall be physically separated from public circulation routes.

14.3.4.3 Vertical Circulation

A. Planning Principles

Primary Mode – Escalators shall be provided as the primary mode of vertical circulation to accommodate normal peak period boarding and alighting passenger flows within station public areas. Elevators may be considered as the primary mode of station vertical circulation at low-ridership stations at the discretion of the Authority.

Secondary Mode – Stairs shall be provided in addition to escalators as required for emergency evacuation. Refer to Section 14.3.5 for means of escape during station evacuation.

Escalator Alternative – At least 1 stair shall be provided between levels for passengers who prefer not to use escalators.

Right-hand Flow – Stairs shall generally be located to the right of a single escalator for a passenger preparing to descend. When stairs are adjacent to two escalators, the stairs shall be located between the escalators. If stairs are wider than 15 feet, the stair may be divided and moved to the outside of the escalators.

Orientation – Stairs and escalators shall be oriented to direct passengers towards their destination and to avoid U-turns.

Future Stair Replacement – Stairs shall be designed so that they may be replaced by escalators if demand requires in the future, if feasible. This includes the stair support structure and space allocations for escalator operational elements.

Vertical Distance – Where vertical circulation is provided in excess of that required for peak flows, an escalator for upward flow shall be provided wherever the vertical travel distance exceeds 10 feet-0 inches. An escalator for downward flow shall be provided wherever the vertical travel distance exceeds 25 feet-0 inches.

B. Escalators

Quantity – Escalator quantities vary by station and ridership. At least 1 extra escalator shall be provided between Concourse and Platform levels as a backup during escalator maintenance.

Installation – Escalators shall be installed at a 30-degree slope between lower and upper working points. Refer to Standard and Directive drawings for additional dimensional criteria. Lifting hooks shall be provided above escalators for initial installation and future replacement.

Specifications – Per Table 14-10

Table 14-10: Escalator Criteria

Escalator Elements	Planning Criteria
Type	Heavy-duty reversible
Operation	Operated either from station control room or locally by key; motion detectors top and bottom for energy conservation
Tread Width	40 inches
Flat Steps	5 flat steps at top landings and 4 flat steps at bottom landings
Speed	Dual-speed, 90 feet per minute and 120 feet per minute
Capacity	70 people per minute
Opposing Escalators	80 feet-0 inches minimum working point to working point
Clear Headroom	10 feet-0 inches absolute minimum above nosing

Emergency Operation – In emergency situations, escalators running in the opposite direction from the exiting flow can be stopped remotely and used as stairs for exiting. Escalators with an emergency stop button shall be provided with accompanying signage.

Weather Protection – Escalators shall be protected from direct rainfall by a roof or canopy.

Queuing Distance – Refer to Section 14.3.4 for escalator queuing requirements.

Side Clearances – Refer to Standard and Directive Drawings for clearances between structural members and floor slabs to allow for escalator truss and finish materials.

Machine Spaces – Each escalator shall be provided with an upper machine space and a lower machine room (or pit) housing motors and other escalator equipment. Machine spaces shall be adequate for machine maintenance and accessible from removable floor cover plates. When located in ceilings above public spaces, machine space within the suspended ceiling shall be concealed. Drainage of escalator machine rooms shall be provided for maintenance and cleaning.

C. Public Stairs

Quantity – Stairs in addition to escalators shall be provided where required to accommodate NFPA 130 emergency egress conditions. Refer to Section 14.3.5 for emergency evacuation criteria.

Width – Stairs required for emergency evacuation shall provide exiting capacity as required to supplement the escalator emergency capacity. Minimum public stair width shall be as required by NFPA 130 or in Table 14-11 (whichever is greater).

Table 14-11: Stair Width Minimums

Element	Minimum Width
Stairs next to escalators	6 feet-0 inches
Platform stairs	6 feet-0 inches
Stair-only entrances	8 feet-0 inches
Emergency stairs	6 feet-0 inches

Alignment – Align lower stair working point with lower escalator working point. Stairs shall slope at 30 degrees to align with escalators.

Queuing Distance – Refer to Section 14.3.4 for stair and escalator queuing requirements.

Emergency Stairs – Emergency stairs shall be provided where escalators and stairs provided for normal operation are insufficient for emergency evacuation of the station. Emergency stairs shall be easily accessible from public areas but shall not be used during normal operation. No ancillary rooms may be accessed from the emergency stairs.

Headroom – Minimum headroom above public stairs shall be at least 10 feet.

Materials – Stair treads and nosings shall be constructed of slip-resistant, robust, non-combustible materials, suitable for and proven to be utilized in high-traffic transportation areas. The leading edge of nosings shall be eased to 1/4-inch to 1/2-inch radius. Risers shall be raked back a minimum 1 inch from edge to back of the tread below.

Where stairs are exposed to weather, provide a floor drain at the bottom of the stair.

Weather Protection – Stairs may be covered depending on level of use and expected level of inclement weather for station region. Where exterior stairs are adjacent to covered escalators, extend covering over stairs in a single roof structure.

D. Ramps

Ramps may be utilized where there are small changes in elevation or for wheelchair access. Ramp width follows horizontal circulation requirements and shall comply with building code

and accessibility requirements. Ramps may be appropriate vertical circulation instead of a small number of stairs.

E. Passenger Elevators

General – Elevators shall be provided and designed for all patrons, including patrons carrying large luggage, strollers, bicycles, stretchers, for passengers in wheelchairs and for the movement of supplies. Wherever access to the platform requires a change of level, an elevator shall be required.

Quantity – At least one elevator shall be provided to connect each station level. Space and structural accommodation shall be provided for the future addition of a redundant passenger elevator between station levels. Two or more elevators between levels may be required initially at Terminal Stations in order to accommodate passenger flow requirements and passengers with luggage.

Location – Wherever practicable, elevators between the Concourse and platforms shall be located near the center of the platform. Elevator doors shall face the platform end and not the platform edges.

Size – Elevators shall be 4,000-pound passenger-type with center-opening doors. Elevators shall be sized to move standard station maintenance equipment between levels.

Speed – Rated travel speed shall be either 125 feet per minute (fpm) or 150 fpm with a maximum wait time of 30 seconds.

Queuing – Refer to Section 14.3.4 for elevator queuing requirements.

Materials and Finishes – Elevators shall be glazed on three sides with clear glass to increase a real and perceived sense of safety. Doors shall be provided with glazed vision panels. Hoistway structure shall be heavy steel framing. Solid wall and ceiling panels shall be Type 304 brushed stainless steel except in marine environments where Type 316 is required. Floors shall be non-slip, durable material proven to be appropriate in a heavy-use transit environment.

Machine Rooms – Elevator machine rooms, where required, shall be located at the lowest level, as close as possible to the elevator.

Weather Protection – Elevator entrances shall be covered to protect passengers and facilities from inclement weather.

F. Service Elevators

General – Service elevators shall be provided at Terminal Stations only for movement of goods, refuse and equipment between station levels for train inspecting, cleaning, restocking and repairs. Passenger elevators shall not be used as service elevators.

Number – There shall be one service elevator serving each platform at Terminal Stations. Service elevators shall be provided at designated Intermediate Stations only where it is

anticipated there will be frequent movement of goods or equipment between the non-public areas and platforms. A service corridor shall be provided either beneath or above track level connected to the non-public station areas.

Capacity – Minimum 3,500-pound capacity service elevators shall be provided.

14.3.4.4 Accessibility

A. Goals

General – Stations shall be designed and constructed to be readily accessible to and usable by individuals with disabilities. Stations shall fully comply with relevant requirements of Title 24 of the 2010 CBC, with the 2010 version of the federal ADA Standards for Accessible Design, and the current version of the ADAAG.

As revisions to the reference standards are issued, they shall become immediately applicable to the design of future stations and related station facilities.

Universal Design – The principle of Universal Design shall be applied to the design of all stations and related passenger facilities. In addition to passengers with mobility, hearing, and sight impairments, stations shall be accessible to passengers with mental impairments, elderly passengers with or without assistants, families with infants and children, and young unaccompanied passengers. Station and related passenger facilities shall be designed for easy access by first-time patrons, non-English speaking passengers, and foreign visitors.

Scope – Station elements used to deliver Universal Design include, but are not limited to, easily recognizable accessible paths, convenient elevators, escalators, and stairs, and clearly visible and audible passenger information systems. Accessible paths shall be uninterrupted from station property boundaries through station entrances, through Concourse, mezzanine, and to the train platforms. Accessible paths shall be designed to equally serve boarding, alighting, and transferring passengers.

B. Miscellaneous Provisions

Accessible Routes – Every public entrance shall be fully accessible. Elevators shall be provided between station levels. Ramps may be used between small changes in elevation. All public station facilities, including station entries, Concourses and platforms, ticket gates, ticket windows and machines, elevators, restrooms, and public amenity spaces shall be fully accessible. Directional signage shall clearly indicate accessible routes.

Site Access – Where public or private property development with public paths connects directly to stations, station plazas, or related station facilities, interface entrances shall be provided that are fully compliant with aforementioned accessibility standards. Furthermore, if such interface with the Authority’s property is not the primary development entrance, a fully accessible path of travel shall be provided from the main entrance, through the development, to the point of interface with the station property.

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Non-public Areas – Accessible provisions for non-public station areas and station staff areas are specified in relevant sub-sections of this chapter.

C. Emergency Egress for the Disabled

Evacuation of disabled passengers and station patrons will vary considerably with individual station configurations. Basic requirements for the egress of disabled patrons, passengers and staff are included in the 2010 CBC as well as CHSTP's Operations and Maintenance documents.

14.3.5 Evacuation from Public Areas

14.3.5.1 Basic Goal

A clear and consistent methodology for passengers, staff, and other station patrons to quickly and safely evacuate stations in the event of an emergency is essential. This methodology shall be consistent with operational policies and as established in NFPA 130 and related safety standards.

This section addresses means of evacuation from the public areas of stations. Evacuation from station non-public areas is addressed in Section 14.3.6. Firefighter access into stations during emergencies is addressed in Section 14.3.1.

14.3.5.2 Causes for Platform Evacuation

A. Fire

Due to the use of non-combustible building materials throughout stations and a high level of fire prevention and detection, station fires are unlikely. Nonetheless, station fires as well as train fires shall be considered as potential emergencies necessitating rapid and complete station evacuation.

B. Evacuation Scenario: Side Platform Station

At Side Platform stations, the evacuation scenario assumes that a fully occupied train enters the station during the peak hour. The platform is already occupied by passengers accumulated during the 15 minutes since the previous train departed and are now waiting to board the arriving train. Arriving passengers shall disembark onto the platform. This combination of peak-hour boarding and alighting passengers shall be rapidly evacuated from the station.

C. Evacuation Scenario: Center Platform Station

At Intermediate Center Platform Stations, the evacuation scenario assumes that two fully occupied trains arrive simultaneously during the peak period and, together with boarding passengers, shall be simultaneously evacuated.

Terminal Center Platform Stations shall take into account the uni-directional scheduling of arriving trains and the limitations of trackwork to consider whether a second fully loaded train, arriving concurrently at a single Center Platform is physically possible. If not, evacuation of a single fully loaded train with boarding passengers is sufficient.

14.3.5.3 Evacuation Goal

A. Principle

In accordance with NFPA 130 and CBC Sections 419 and 433, sufficient routes shall be available to evacuate the POL from the affected station platform in 4 minutes or less and from the most remote point on the platform to a point of safety in 6 minutes or less.

B. Multiple Escape Routes

Evacuation routes shall be planned so that a passenger confronted by a fire can turn away and make a safe escape. To achieve this goal the maximum travel distance to an escape route such as an escalator, stair, passageway, or entrance shall not exceed 325 feet.

14.3.5.4 Evacuation Components

The following factors shall be considered in emergency evacuation planning.

A. Peak Period

The emergency occurs during the peak 15 minutes of the peak hour at the ultimate peak design year.

B. Platform Occupant Load

Maximum POL is based on the evacuation scenarios described above. Platforms shall provide a minimum 10 square feet per occupant during emergency conditions or the minimum dimension shown in Section 14.3.2.1, whichever is greater.

C. Platform Egress

An egress point can be the first riser of a stair or escalator, a horizontal exit with an appropriate door or gate that exits to grade (including an exterior refuge zone from a Center Platform), or a fire-rated door (alongside platforms or at the ends of Center Platforms if a refuge zone is provided at the end of the platform).

D. Vertical Circulation

Only stairs and escalators may be used for evacuation between station levels; elevators are not considered for evacuation. Escalators normally moving in the direction opposite to evacuation shall be remotely stopped and used as stairs. One escalator is assumed to be out of service. For vertical circulation capacities, refer to Table 14-12.

E. Gates

All ticket gates, oversized gates and emergency gates are available and can be opened by station staff for free, full-width (non-turnstile) passage in the exit direction. For gate capacities, refer to Table 14-12.

Table 14-12: Capacities of Station Evacuation Elements

Element	Minimum Width
Escalators (fixed 40-inch tread width)	1.41 people per inch per minute x 40 inches = 56 ppm
Stairs	1.41 people per inch per minute
Fare Gates	50 people per minute
Oversized and Emergency Gates	2.08 people per inch per minute

F. Walking Speeds

For calculation of walking speed assumed for station evacuation, refer to Table 14-13.

Table 14-13: Station Walking Speeds

Element	Minimum Width
Horizontal evacuation on platforms	124 feet per minute
Horizontal evacuation on Concourse	200 feet per minute
Vertical evacuation (up direction)	48 feet per minute
Vertical evacuation (down direction)	60 feet per minute

G. Place of Ultimate Safety

Elevated Stations – Where platforms are open to the elements and the Concourse is below, the place of ultimate safety may be the Concourse level.

At-Grade Stations – Where platforms are located at grade level with the Concourse above or adjacent to the platform or tracks, the point of ultimate safety shall be a point outside the station enclosure.

Underground Stations – The place of ultimate safety shall be an uncovered public thoroughfare at ground level outside the station.

14.3.5.5 Determining Means of Escape from Stations

A. Normal Operation

The station components described in Sections 14.3.3 and 14.3.4 for normal operation shall comprise the baseline station plan. Normal operation layout shall be tested against the 6-minute evacuation standard. If the normal exiting routes are inadequate for emergency evacuation, additional capacity for evacuating the POL shall be provided.

B. General Methodology

Confirm the capacity of escalators and stairs to evacuate the platform in less than 4 minutes as follows:

$$\text{POL} \div \text{Platform Egress Capacity} < 4 \text{ minutes}$$

- Confirm the capacity of all gates to evacuate the POL freely within 6 minutes or less.
- Confirm the capacity of all evacuation elements to evacuate the platform from its most remote point to a point of safety in 6 minutes or less. Evacuation time considers the following factors:
  - Walking time on the platform
  - Walking time between platform and Concourse
  - Walking time on the Concourse to a point of safety
  - Walking time between Concourse and grade level (where applicable)

Where multiple entrance/exits are planned, the longest walking distance shall be used to calculate Concourse walking time.

C. Excessive Evacuation Time

If evacuation time exceeds 6 minutes, capacity shall be increased or evacuation distances shortened. Adding dedicated emergency exit stairs is preferable to adding escalators or public stairs, considering they are more economical and would be needed only in the case of emergency. Adding emergency gates is preferable to adding Fare Gates, considering they are more economical and would be needed only in the case of emergency.

14.3.6 Non-Public/Station Support Areas

This section pertains to non-public areas of the station required for the operation and maintenance of the station and the system. These include passenger service areas, station and system operation offices and other ancillary spaces including maintenance and building services.

Size – Refer to Room Data Sheets for minimum dimensional requirements for non-public areas. Room sizes and numbers may vary between stations depending on the station’s location, type and function. Where room areas and/or heights are not indicated, a reasonable amount of space anticipated for each specific station shall be provided.

14.3.6.1 Passenger Service Areas

Passenger service spaces require public interface with station patrons. As such, they shall be adjacent to station public areas, preferably at ground level. These spaces shall be consistent throughout the system in order to provide continuity and familiarity to passengers and station staff.

A. Lost and Found

Function – Space is used to store and manage passenger’s lost items as well as to collect and return these items to and from passengers.

Location – Concourse Free Area adjacent to the Station Manager's office.

Provisions – At Intermediate Stations, minimum area of 80 square feet; at Terminal Stations, minimum area of 120 square feet. A door opening into the Concourse Free Area as well as an interior door connecting with the Station Manager's office shall be provided. Storage shelving and an internal passenger service counter shall be provided.

B. Police Office

Function – Selected stations shall provide an office for police responsible for station surveillance, passenger interface and railroad security.

Location – Concourse Free Area, near a station entrance, between public and non-public areas, adjacent to the Security office.

Provisions – Minimum area 160 square feet. A passenger service and observation counter shall be provided. Some stations may require holding cells and/or canine support facilities.

14.3.6.2 Standard Station Operation Offices

These back-of-house areas are required at every station but require no public interface. Rooms and spaces shall be arranged according to function and have separate non-public accesses. Access control shall be appropriate to each function. It is preferable for these offices to be located at Concourse ground level unless otherwise indicated. The following is a non-exhaustive list of these spaces.

A. Station Manager's Office

Function – This serves as the office for the Station Manager.

Location – Adjacent to other non-public administrative offices.

Provisions – Minimum area 270 square feet.

B. Station Control Room

Purpose – At Intermediate Stations, the Station Control Room (SCR) is where passenger circulation, ticketing, fare control, security, and building maintenance operations are monitored and controlled. The SCR may also function as an incident-response command center. This will be the place where first responders would coordinate activities with station personnel in the event of an emergency or security incident.

Local train-control capability within the immediate vicinity of the station shall also be available at this location. In the event of a large-scale train-control system failure, it shall be possible to move trains on a station-to-station basis by a station train dispatcher working under the direction of the train dispatcher in the central control facility until system control for that territory can be restored. This train control component of the SCR would not be staffed under normal conditions.

Location – Designers need to be familiar with the operating plan and shall coordinate their efforts with the Core Systems Designer to determine the appropriate location and configuration of any such facilities at Intermediate Stations.

Provisions – Minimum area of 1,100 square feet. Access flooring for underfloor cable routing shall be provided. Layout for the SCR shall be in accordance with a system-wide standard.

C. Station Computer Room

Function – The Station Computer Room houses the servers that are needed in order to operate the ticketing and station operation systems and for communication with the Operations Control Center (OCC) and/or Regional Control Center (RCC).

Location – Adjacent to the SCR and/or Operation Maintenance Office.

Provisions – Minimum area 500 square feet. Controlled heat and humidity and a link to the Uninterruptible Power Supply (UPS).

D. Ticket Administration Office

Function – Used for non-public administrative ticketing functions.

Location – Adjacent to the Ticket Sales Office.

Provisions – Minimum area 160 square feet. Cash handling and ticket storage shall be provided in an adjacent secure room.

E. Cash Handling and Ticket Storage Room

Function – Used for processing cash received from ticket sales and for storage of blank tickets.

Location – Adjacent to the Ticket Administration Office. A secure route shall be provided from this area to a place where money and tickets can be transferred to money transport vehicles.

Provisions – Minimum area 260 square feet including a partitioned 60 square feet for ticket storage. A safe shall be provided in this room for temporary storage of tickets and cash.

F. Security Office

Function – This office provides a control center for station security.

Location – The Security Office shall be located adjacent to the Station Administration Office and the Police Office.

Provisions – Minimum area 160 square feet .The office shall have video screens to monitor the station area Closed-Circuit Television (CCTV).

G. Facility Maintenance Office

Function – Building services administration and maintenance.

Provisions – Minimum area 330 square feet.

H. Staff Break Room

Function – For station staff on break.

Location – Grouped with other staff functions.

Provisions – Minimum area 200 square feet or as required to provide 25 square feet per staff within a typical shift. Basic kitchenette facilities and staff lockers shall be provided for storage of personal items.

14.3.6.3 Special Station Operation Offices

These back-of-house areas are required only at designated stations and require no public interface. It is preferable for these offices to be located at Concourse level unless otherwise indicated. The following is a non-exhaustive list of these spaces.

A. Terminal Control Facility

Function – Terminal Control Facilities (TCFs) are proposed to have immediate supervisory oversight over train and passenger operations within each specific terminal. TCF personnel shall control local operation of the Public Address/Customer Information Sign system, and directly manage terminal rail and facility operations on a local level. Dispatching of trains shall be controlled by main line dispatchers at the OCC or RCC who shall interface closely with TCF personnel. Train dispatching capability shall be available at the TCF if necessary in emergency circumstances. The Fire Command Center and control of the Fire Alarm System shall be located in the TCF. The Terminal Manager and Assistant Terminal Managers shall monitor operations from the TCF.

Location – TCFs shall be required at Terminal Stations and select Key Intermediate Stations acting initially as Terminal Stations.

Provisions – The TCF minimum area shall be 1,500 square feet at Terminal Stations, and may be less at Key Intermediate Stations. The room shall have access flooring for underfloor cable routing to support communications and train monitoring equipment. Basic kitchenette facilities and staff lockers shall be provided for storage of personal items for immediate occupants.

B. Incident Room

Function – Incident Rooms, located adjacent to but separate from the TCF, shall be equipped with communications and train-monitoring equipment to assist senior CHSTP personnel in the strategic management of significant operating incidents, without interfering with the tactical activities taking place in the TCF proper during such an incident. In situations where access to the TCF is not affected by the event, emergency responders and other support personnel may choose to join railroad managers in the Incident Room to assist in the management of an event.

Location – Incident Rooms shall be located at terminals and Key Intermediate Stations where there is a TCF, and shall be located immediately adjacent to the TCF.

Provisions – An Incident Room's minimum area shall be 750 square feet at Terminal Stations, and may be less at Key Intermediate Stations.

C. Building Management Office

Function – Terminals and select Key Intermediate Stations shall have a Building Management Office that will monitor or control building systems at the facility by means of a Building Management System. It is expected that included in the items to be monitored or controlled shall be the following:

- Elevators
- Escalators
- Station power and electrical systems
- Heating, ventilation, and air conditioning (HVAC)
- Emergency ventilation
- Storage of station/systems plans and inspection records
- Other building maintenance and supervisory control and data acquisition (SCADA) systems

Location – The Building Management Office shall be located near the Operations Maintenance Office and TCF at terminals and select Key Intermediate Stations.

Provisions – The Building Management Office shall be a minimum area of 1,200 square feet at Terminal Stations, and may be less at Key Intermediate Stations. At Intermediate Stations, functions shall be monitored from the SCR.

D. Incident Command Post

Function – An Incident Command Post (ICP) is defined by NFPA 130 as the location at the scene of an emergency where the Incident Commander is located and where command, coordination, control, and communications are centralized. An underground facility, such as a major rail terminal, is required to have an ICP of fixed location at street level that provides all the systems and resources necessary to support the command and control functions needed by emergency responders.

Major underground terminals, such as the Transbay Transit Center in San Francisco, shall have fixed-location ICPs associated with them.

Location – The Incident Command Post shall be located at street level separate from but in general proximity to station.

Provisions – The Incident Command Post shall be **a** minimum area of 1,500 square feet at select Terminal Stations.

E. Training and Meeting Room

Function – Staff meetings, staff training, and emergency command.

Location – Training and meeting rooms shall be required at designated stations only, adjacent to the Station Administration Office.

Provisions – Training and meeting rooms shall be a minimum area of 200 square feet.

F. Operation Maintenance Office

Function – Administration work and parts/equipment storage for the system operations and engineering staff.

Location – An Operation Maintenance Office shall be required at Terminal Stations and other designated stations, accessible to the loading dock.

Provisions – An Operation Maintenance Office shall be a minimum area of 1,100 square feet.

G. Staff Locker Rooms

Function – Personal storage and separate showering for male and female staff during shift.

Location – Staff locker rooms shall be required at Terminal Stations and Key Intermediate Stations with turnback service only and grouped with other staff functions.

Provisions – Staff locker rooms shall be sized as required for the estimated staff numbers during a typical shift. Individual lockable lockers and benches shall be provided for changing clothes. Shower rooms, separate from the locker area, shall be provided. Size and quantity to be determined by CBC.

H. Staff Restrooms

Function – Men’s and women’s staff restrooms shall be provided (in addition to public restrooms) in accordance with CBC.

Location – Staff restroom shall be required at Terminal Stations only, and shall be located in the Station Operations Office area and adjacent to the Staff Locker Room and Staff Break Room. Staff will use public restrooms at Intermediate Stations.

Provisions – The staff restroom size and fixture quantity shall be determined by CBC.

I. Transportation Agency Offices

Function – Local or regional transportation agency office functions.

Location – Transportation agency office shall be located at selected stations where transportation agencies request offices within station.

Provisions – Transportation agency office size shall be requested by local agencies.

14.3.6.4 Maintenance Support Spaces

Other station ancillary spaces for maintenance or storage may include the following.

A. Refuse Storage Room

Function – Space to store an appropriate volume of recycling and waste produced within the station during a maximum 3-day period between pickups. Trash compacting equipment shall be provided as appropriate for the anticipated quantity of refuse.

Location – Ground level where collection trucks can collect, away from public areas and outside of the station where feasible.

Provisions – Minimum area of 150 square feet or as required to accommodate current recycling requirements with flexibility to accommodate future changes.

Terminal Stations shall require additional area to accommodate waste generated over 3 days on trains, within station, and by commercial establishments within the station. A hose bibb and floor drain shall be provided.

B. Cleaning Supply Rooms

Function – Storage space for cleaning supplies.

Location – Adjacent to the Concourse Free Area, the Concourse Paid Area, and the platform. Additional cleaning supply rooms shall also be located near each set of toilet facilities.

Provisions – Minimum area 80 square feet. A janitor's sink, mop, and broom racks shall be provided.

C. Station Storage Rooms

Function – General storage.

Location – Adjacent to the Concourse Free and Paid Areas, and on the platform.

Provisions – Concourse minimum area 150 square feet. Platform minimum area 100 square feet.

D. Landscape Maintenance Room

Function – Storage of landscaping tools and supplies.

Location – Opening directly to station exterior.

Provisions – Minimum area 100 square feet.

E. Miscellaneous Rooms

Function and minimum areas in the Concourse non-public area:

Table 14-14: Miscellaneous Rooms

Space Name	Minimum Area Required	Special Provisions
Storage and Battery Charging	200 square feet	For electric carts
Staff Equipment Storage	60 square feet	
Consumables Storage	60 square feet	
Advertising Storage	60 square feet	
Materials Storage	60 square feet	
Small Materials Storage	60 square feet	

F. Loading Zone

A station loading zone and service entrance shall be sized as appropriate for each Intermediate Station to accommodate minor station-related deliveries, ticket revenue handling, trash collection, police and security-related access, and deliveries to retail concessions within the station. Loading zones and related functions shall be separated from the main station entrances and circulation patterns to prevent disruption of pedestrian and vehicular flows.

G. Loading Dock

At Terminal Stations, a loading dock for receiving and delivery of onboard services supplies shall be provided. Size shall be as appropriate to accommodate major station-related deliveries, ticket revenue handling, trash collection, police and security-related access, and deliveries to retail concessions. Dock height shall be as appropriate for medium-sized delivery trucks.

The loading dock and related functions shall be separated from the main station entrances and circulation patterns to prevent disruption of pedestrian and vehicular flows.

14.3.6.5 Terminal Station Operations Facilities

At Terminal Stations or other stations as designated in the station operations plan, space for terminal administration, support of train crews, and for rolling stock maintenance prior to turning back shall be provided.

A. Terminal Administration Offices

Function – Terminal administrative tasks are performed in this space. Some staff may have dedicated workspaces while others may share.

Location – Adjacent to the Station Manager's office.

Provisions – Minimum area 100 square feet per assigned staff.

B. Train Crew Support

Spaces required for train crews at Terminal Stations and Key Intermediate Stations with turnback service, which may include shift changes and spaces for crews to wait while trains are being turned back, include the following:

Table 14-15: Train Crew Support Spaces

Space Name	Minimum Area Required	Special Provisions
Shift supervisor Office	400 square feet	Space for four shift supervisors
Administrative Support Office	100 square feet	Space for one support staff
Train Crew Restrooms	200 square feet	Includes male and female
Train Crew Lounge	750 square feet	Locate adjacent to restrooms.
Ready Room	300 square feet	
Train Crew Lockers/Showers	500 square feet	65% male, 35% female, locate adjacent to restrooms

C. Rolling Stock Maintenance

Spaces required for minor maintenance and inspection of the trains and platform include the following:

Table 14-16: Rolling Stock Maintenance Spaces

Space Name	Minimum Area Req'd.	Special Provisions
Gang Foreman Office	100 square feet	
Car Inspector Office	120 square feet	Space for two car inspectors
Cleaners' Room	120 square feet	One for each platform, each to accommodate two cleaners
Maintenance Locker Room	200 square feet	Includes showers and restrooms
Refuse Rooms	75 square feet	Three rooms on platform level
Maintenance Equipment Storage Lockers	160 square feet each	Three rooms located at platform level, distributed along the length of the platform under escalators or stairs for tool and miscellaneous storage. Water and power shall be provided.
Cleaning machine storage	660 square feet	Includes charging facility
General Storage Lockers	400 square feet total	Distribute along the length of the platform, under escalators or stairs where practicable, for restocking of trains.

D. Commissary Requirements

Spaces required at Terminal Stations to provide for commissary service on the HSTs include the following:

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Table 14-17: Commissary Spaces

Space Name	Minimum Area Required	Special Provisions
Commissary Office	120 square feet	
Food Storeroom	800 square feet	Accessible from loading dock
Commissary Locker Room	350 square feet	Lockers, showers, restroom

Unless the Terminal Station includes a separate service platform, commissary spaces require direct access to station platforms. The preferred locations are above or below the ends of platforms and adjacent to, or in close proximity to, the station service elevators

E. Service Access

General – Terminal Stations require service access between platforms, the back-of-house areas of the station, and the station loading zone. Ideally, these access routes will not cross public circulation routes within the station. These corridors will be used by station staff and maintenance personnel and will not be accessible to the public.

Service Elevators – At Terminal Stations, as described in Section 14.3.4, dedicated service elevators shall be provided to each platform, connecting with a service corridor that passes above or below the platforms and providing direct non-public access to the station's back-of-house facilities. It will be desirable to standardize the location of these service elevators at HST stations (i.e., at the north end or south end of the platforms), to facilitate train provisioning and servicing. This will require coordination with the trainset design and the developers of the overall operating plan.

Service Corridors – Certain station-related service corridors (such as the corridor linking the Cash Handling and Ticket Storage Room with the loading zone) shall be kept separate from service corridors serving the commercial zones of the station. Concrete floors shall be hardened wherever cash carts will be moved.

F. Turnback Stations

Designated Key Intermediate Stations may be operated as turnback stations. These stations shall be provided with crew waiting and changing spaces.

14.3.6.6 Building Service and Plant Rooms

Potential systems to consider include, but are not limited to environmental control, electrical, fire protection, and plumbing and drainage. Station design shall accommodate the building systems and meet the requirements of applicable codes. Additionally, facilities necessary to meet LEED Silver standards and corresponding efficiency and energy use standards shall be included, as determined by the Designer.

Access and hoisting provisions shall be provided for installation and future replacement of station equipment. Clear ceiling height in equipment rooms shall be 16 feet-0 inches minimum to permit equipment placement and overhead utility routing.

A. Environmental Control

Spaces for the environmental control system may include the following:

- Condensing Unit Room
- Air Handling Unit Room
- HVAC Room
- Tunnel Ventilation Fan Room (underground stations only)

B. Electrical System

Substation – An external Facility Power Substation is required on the station site for the purpose of providing normal, backup, and emergency standby power to the station. The substation shall be located within a 10,000 square feet fenced area that contains high voltage (HV) switchgear, HV transformers, emergency generator, and a fuel storage tank. The generator and adjacent fuel tank shall be a minimum of 25 feet-0 inches from any station structure and separated from adjacent properties. Service vehicle shall provide access.

Station – Spaces for the facility power system within the station may additionally include the following:

- UPS Room – 900 square feet. Two rooms required, one at each end of the station for low voltage (LV) distribution, transforming, and emergency power
- Battery Room – 200 square feet. Two rooms required, one room at each end of the station for LV batteries.

C. Fire Protection

Spaces for the fire protection system shall include the following, sized by designers as required:

- Fire Pump Room
- Fire Water Tank Room
- Fire Control Center

D. Plumbing and Drainage

Spaces for the plumbing and drainage systems shall include the following and shall be sized by designers as required:

- Sump Pump Room
- Ejector Room

14.3.6.7 Core Systems Spaces

Facilities required for Core Systems are addressed in other chapters of this Design Criteria. Refer to the *Communications* chapter for detailed design criteria for communications rooms. Station design shall accommodate the Core Systems and operational requirements, including the following spaces for train control and communications:

Table 14-18: Train Control and Communications Spaces

Space Name	Minimum Area Required	Special Provisions
Train Control and Communications (TCC) Room	1,915 square feet	For train control and communications equipment
Entrance Facility Room	240 square feet	For entry of service cabling into the building. May be co-located with the TCC Room
3rd Party Telecom Room	120 square feet	
Communications Closets	130 square feet each	Locate close to center of each 10,000 square feet of station floor area

14.3.6.8 Room Data Sheets

Refer to Appendix 14-A for detailed design data relevant to each of the preceding station spaces.

14.3.7 Interior Environment

14.3.7.1 Lighting

Lighting of passenger stations and surrounding site areas shall be consistent in quality and quantity throughout the system.

Station lighting shall promote safety by properly illuminating exit routes and potential hazards. Varying lighting and illumination levels shall be used to differentiate station functions, including circulation, entry, fare collection, waiting areas and platforms. Illumination shall provide uniform distribution and minimize glare. Direct lighting for Concourse and platform areas shall be used. Indirect lighting is not acceptable for illumination of floor areas.

Minimum average illumination under normal operation is shown in the *Facility Power and Lighting Systems* chapter.

14.3.7.2 Electrical

A. <u>System Requirements</u>

Electrical systems include power supplies (HV, LV, and emergency), normal and emergency lighting, and grounding and lightning protection. Facilities to support electrical operation of the station may include standby generators, switchboards, uninterruptible power systems, on-site power generation such as solar power generating facilities, and electrical distribution facilities.

B. Emergency Provisions

When normal and backup power sources are interrupted, a standby emergency supply generator shall provide station power to select electrical loads connected to the 480 volt AC generator bus. Standby emergency supply generator shall provide power for electrical loads such as fire protection, emergency lights, emergency signage, telecommunications systems, elevators (typically one in operation to get to the incident floor), ventilation, station control, UPS system, and LV DC battery supply systems (that provide control power to HV switchgear, etc.). The emergency standby generator shall have fuel capacity to operate for at least 30 hours. In addition to an emergency standby generator, uninterruptable power supply equipment shall be provided for the following electrical loads:

- Emergency lighting with a minimum battery capacity of 90 minutes
- Communication and train control electrical loads with a minimum battery capacity of 4 hours

C. Electromagnetic Compatibility

All electrical and electronic equipment in the station shall follow CHSTP Electromagnetic Compatibility Program Plan (EMCP) criteria for cable, grounding, equipment design, facility power, motors and controllers, equipment room locations, equipment emission and immunity limits, Fire Command Center-type accepted radio equipment, and human exposure to electric and magnetic fields.

Equipment covered by EMCP criteria includes the following:

- HST Core Systems' equipment, including for traction power, communications, and train control
- Station equipment, including fare collection, security and public safety communications, public communications including public address and telephones, operations information, passenger information, environmental control, fire detection and protection, lighting, auxiliary equipment
- Shared communication and control equipment with other rail operators

14.3.7.3 Plumbing and Drainage

General – Plumbing and drainage systems include domestic water supply, stormwater drainage, sewer and wastewater drainage, and fire protection water supply. Detailed plumbing and drainage requirements in stations are described in a separate chapter of this manual.

Piping – Where domestic water piping or drainage piping enters a room through an outside wall, the pipe shall be concealed from public view. Valves shall be concealed in valve boxes not exposed to public view.

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Drains – Wherever floor drains are required, floors shall be sloped a minimum of 1/8 inch per foot. Drain locations shall be coordinated with architectural floor finish patterns to minimize cutting of materials.

14.3.7.4 Fire Detection and Protection

General – Fire protection criteria are described in the *Fire Protection* chapter.

Automatic Fire Sprinklers – Placement of automatic fire sprinkler heads shall be coordinated with other mechanical and electrical equipment such as air supply and return, lighting fixtures, public address speakers, etc. Pipes in public area ceilings shall be concealed.

Fire Suppression System – An appropriate fire suppression system shall be provided as required by code for specific room functions such as train control and communications rooms.

Fire Hose Cabinets (FHC) – In Concourse public areas, recessed fire hose cabinets shall be provided and integrated into the standard wall finish module. FHCs on platforms may be floor mounted and conform to a system-wide design. Hinged doors, clearly labeled "FIRE HOSE CABINET" with locks keyed alike shall be provided.

Fire Extinguishers – Fire extinguishers, type and spacing as required by code, shall be recessed into walls in public areas or surface mounted in non-public areas.

14.3.7.5 Noise Control and Acoustical Design

Purpose – Noise generated by the train, patrons, external sources, and building systems shall be controlled and reduced through station design. Stations shall be designed to allow for normal conversation, ensure that public announcements can be clearly understood, and allow for communication during emergency conditions.

Mitigation – Appropriate mitigations shall be considered inside the station and adjacent to the station. This may include sound absorption materials installed in under-platform areas, ceilings and walls of platform and Concourse areas. Acoustical treatment in stations shall meet acoustical performance criteria as well as architectural, safety and maintenance criteria, as shown in Table 14-19. Performance criteria include – low flammability, low smoke development, non-toxicity, low volatile organic compounds, low maintenance, and vandal-resistance, resistance to water, rotting, and odor.

Noise Barriers – Where through-trains pass through stations, noise barriers shall be required between through and stopping tracks. Perimeter noise barriers shall also be required to minimize train noise impacts on surrounding buildings and communities.

Reverberation Time – For public station areas, reverberation time shall be a maximum of 1.5 seconds at 500 Hertz (Hz). Maximum station noise levels are shown in Table 14-19.

Table 14-19: Station Noise Levels

Location	Maximum Noise Level Permitted
Platform (stopping trains entering and leaving station)	80 dBA
Platform (trains stopped at station)	70-75 dBA
Platform (train passing station)	85-90 dBA
Concourse (near platform with train passing station)	75-80 dBA
Public Station Areas (with mechanical, HVAC or other station equipment operating)	55 dBA
Public Station Areas (tunnel or station ventilation operating in emergency status)	70-80 dBA
Offices and Small Meeting Rooms	40-45 dBA
Control Rooms	35-40 dBA
Computer and Equipment Rooms	55 dBA
Building Plant Rooms (where this cannot be met, warning signs shall require staff to wear hearing protection)	85 dBA

Notes:

1. Noise levels measured by a slow response time constant averaged over 1 second.
2. Center of platform shall be used as the reference measurement location.
3. Noise levels due to train-generated noises are design objectives only.

14.3.7.6 Vibration Minimization

Ground- and structurally-borne vibration generated by the train and equipment shall be addressed through station, track, and structure design. Passenger and staff comfort shall be maintained and station elements designed to withstand vibration. Vibration from station equipment shall be mitigated to acceptable levels. The vibration impacts to surrounding areas shall be minimized.

Equipment that generates vibration shall be isolated from other station elements to reduce vibration-induced fatigue of other components and equipment. Mechanical and electrical equipment shall be set on isolation pads.

14.3.7.7 Environmental Control Systems

Locations – HVAC requirements will vary based on station type, station area weather, and other factors. LOS will also vary within the building based on specific room requirements. HVAC shall be provided in Concourse areas but not on platforms except for underground stations.

Temperature Control – Temperatures for enclosed public station areas, with the exception of the station operations areas and other unoccupied areas, shall be kept between 65°F and 75°F with a maximum of 65 percent relative humidity. The SCR, ancillary areas, computer rooms, and communication equipment rooms shall be kept cooler with a maximum relative humidity of 60 percent. Main substations, standby generators, the central air conditioning plant, and Air Handling Unit rooms shall be kept below 100°F.

Ventilation – Ventilation shall be provided in the Free, Paid and Operations Areas. Refer to the *Mechanical* chapter of this manual.

Redundancy – Redundancy is not required for environmental control systems for public areas. Back-up mechanical HVAC systems shall be provided for areas and equipment rooms that are essential to HST operations, including the SCR, Building Maintenance Office, System Equipment rooms, and other supporting facilities.

Controls – Temperature and humidity shall be controlled from the SCR.

Space Requirements – HVAC space requirements may include chiller room, air handling unit room, control room, and ventilation room among other spaces. Refer to Section 14.3.6 and Room Data Sheets for additional information.

14.3.7.8 Flood Protection

Site – Stations sites shall be analyzed for proximity to a flood plain or other potential sources of water infiltration. Openings into stations shall be protected to a minimum of 4 feet-0 inches above the 100-year design flood level.

Entrances – Station entrances shall be protected, as appropriate, by steps, a sloped plaza apron, or ramping up to a landing to include minimum flood protection of 2 feet-0 inches above surrounding grade level as anticipated for the maximum design-year flood level.

Waterproofing – Portions of station facilities identified below the water table shall be appropriately waterproofed to prevent infiltration of ground water for the design life of the facility.

14.3.8 System-wide Furniture, Fixtures, and Equipment

In addition to equipment described elsewhere in this design criteria, the platforms and Concourse, both Free and Paid Area, shall be provided with the following system-wide furniture, fixtures, and equipment. System-wide furniture, fixtures, and equipment do not add square footage to the station footprint. These elements shall occupy portions of the spaces described in Sections 14.3.2 and 14.3.2.3.

Where required, access for control/data and power conduits shall be provided.

14.3.8.1 Furniture

A. Seating and Benches

Location – Concourse Free Area, Concourse Paid Area, platforms.

Within Concourse waiting areas, seating and benches shall be organized into one or more seating groups without obstructing passenger circulation.

On platforms, seating shall be oriented parallel to the track within the central zone between vertical circulation elements or columns and protected from the weather. Seating shall be

located adjacent to each car. Platform signage to identify where each numbered car will stop shall be provided.

Quantity – The minimum number of seats to be provided is listed in Table 14-20.

Table 14-20: Station Seating

Symbol	Description	Formula [1]
S_f	Seating at Concourse Free Waiting Area	$[(P_{15B} \times 1.1) + (P_{15A} \times 0.1)] \times 0.25$
S_p	Seating at Concourse Paid Waiting Area	$P_{15B} \times 0.25$
S	Seating on Platforms	8 seats per car (except where seating might obstruct passenger circulation)

[1] P_{15B} = Peak 15-minute boardings; P_{15A} = Peak 15-minute alightings

Description – Seating shall be designed with armrests to discourage lying down. Materials shall be corrosion resistant where exposed to exterior elements. Interior seating shall be cushioned and upholstered with a washable, heavy-duty vinyl. Seating shall be secured to the floor with vandal-resistant fasteners.

B. Waste and Recycling Receptacles

Location – Concourse Free Area, Concourse Paid Area, exterior station approaches.

Receptacles shall be located adjacent to entrances, ticketing facilities and waiting areas. Locations shall not obstruct passenger circulation. Receptacles shall be protected from direct weather exposure.

Quantity – As appropriate for each particular station layout.

Description – Triple units for waste, cans and bottles, and paper recycling shall be provided. Materials shall be non-corrosive.

C. Passenger Information Counter

Location – Terminal Stations in the Concourse Free Area, close to the main entrance.

Quantity – One per Terminal Station.

Description – The Passenger Information Counter shall be a system-wide standard design. Each counter shall be approximately 100 square feet. A freestanding counter shall be staffed with at least 1 information agent to provide passengers and station visitors with general information regarding train schedules and use of the high-speed rail system. These counters can also provide information to departing passengers about the local city and modes of connecting transportation available outside the station.

At Intermediate Stations, these passenger services shall be provided at the PSB as described elsewhere in this section.

14.3.8.2 Fixtures

A. Station Assistance Telephone

Location – Concourse Free Area, Paid Area, and platforms

Station Assistance Telephones, sometimes called "White Courtesy Phones," offer passengers another means to obtain information or assistance.

Quantity – One Station Assistance Telephone shall be placed in each Paid and Free Waiting Area and located at a maximum 300-foot walking distance along the length of each platform.

Description – Refer to Section 14.3.9 - Station Information for additional information.

B. Drinking Fountains

Location – Concourse Free Area, Concourse Paid Area.

Quantity – One drinking fountain shall be located adjacent to each waiting area, and removed from the main circulation paths.

Description – Dual height stainless steel, wall-mounted drinking fountains, in accordance with applicable codes.

C. Public Telephones

Location – Concourse Free Area.

Public telephones shall be located in groups of at least 2 phones close to station entrances, adjacent to the Concourse Free Area but outside of primary circulation spaces.

Quantity – P_{15B} x 0.01

Description – Coin-operated, wall-mounted or free-standing phones shall be provided by the local telephone utility service. Telephones shall comply with ADA accessibility requirements. When wall-recessed, public telephones shall be integrated into the station finish module as described in Section 14.3.10.2.

D. Closed-Circuit Television

Location – Platforms, other locations as indicated in Room Data Sheets.

Quantity – As required on platforms to monitor the public area of each platform, with particular emphasis on platform edges, stair and escalator landings, elevator entrances and platform ends.

Description – Ceiling mounted. Refer to the *Communications* chapter.

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E. Clock

Locations – Concourse Paid Area, adjacent to the primary circulation route to platforms.

Quantity – One per station.

Description – Analog clock with oversized face, minimum 36-inch diameter. Wall mounted, ceiling hung or freestanding floor mounted, minimum 10 feet above finish floor.

F. Map and Information Panel

Location – Concourse Free Area.

Quantity – One vicinity map/information panel close to each station entrance/exit, either integrated into the wall finish module or a freestanding kiosk.

Description – Information shall also include racks for printed train timetables and other pertinent passenger information. Information panels and kiosks shall be a system-wide design and provide information about HST service, including train schedules, fares and policies.

14.3.8.3 Equipment

A. Passenger Service Center

Location – Between Concourse Free Area and Paid Area within the Fare Collection Line.

Quantity – One at each Fare Gate array between Free and Paid Areas.

Description – The Passenger Service Center provides information and assistance to station passengers as they enter or leave the Paid Area. The Passenger Service Center shall be a system-wide standard freestanding unit, approximately 100 square feet in area. Passenger inquiry windows shall be provided on the Concourse Free and Paid Areas of the Passenger Service Center. Queuing space as shown in Table 14-7 shall be provided. Agent access to the Passenger Service Center shall be via a main door on the paid side of the booth. Finish materials shall be stainless steel up to approximately 4 feet-0 inches height and fully glazed above.

Equipment – The Passenger Service Center shall be fully enclosed, lighted, and ventilated. Counter work space for agent's computer terminal shall be provided. The public address and in-station dynamic signage systems shall be controlled from this booth as well as the station control room. A communications link between the Passenger Service Center, the SCR or TCF, and the OCC shall be provided to facilitate timely and accurate dissemination of train information to the public.

B. Platform Agent Booth

Location – Platform Agent Booths shall be considered at Terminal Station platforms only, and placed at the Center Platform to allow clear visual surveillance of the entire platform length.

Quantity – One per Terminal Station platform as appropriate. Where Terminal Stations are provided with multiple platforms and Operations requires a platform agent, each platform shall be provided with one Platform Agent Booth.

Description – This booth is used to monitor train Terminal Station arrivals and departures and platform passenger circulation. At Intermediate Stations, the monitoring of passengers entering and exiting trains will be done by the train crew. The Platform Agent Booth shall be a system-wide standard freestanding unit, approximately 100 square feet in area. Each Platform Agent Booth shall be staffed with an agent and therefore shall be provided with a work counter, computer terminal, and communications equipment.

Finish materials shall be stainless steel up to passenger window height and fully glazed above. The Platform Agent Booth shall be fully enclosed, lighted and air conditioned.

Equipment – Public address capabilities and control of the in-station dynamic signage shall be integrated into this booth. This facility requires a communications link with the TCF and the Central Control Facility to facilitate timely and accurate dissemination of train information to the public.

C. Automated Teller Machines (ATM)

Location – Concourse Free Area

Quantity – Space for one ATM shall be provided adjacent to each ticket sales office.

Description – As provided for the convenience of passengers buying tickets. ATMs shall be freestanding and separated from passenger circulation flows or integrated into the station wall finish module.

14.3.9 Station Information

14.3.9.1 General Principles

The key to passenger wayfinding is logical and consistent station planning, conforming to the passenger circulation principles. Information systems shall be provided as additional support to assist passengers in finding their way to, within, and from HST stations and related facilities. Information systems shall reflect the system's commitment to Universal Design and passenger friendliness. The key features of station information are described in this section.

14.3.9.2 Signage and Graphics

Purpose – Signage and graphics shall be provided throughout stations as the primary visual component for passenger wayfinding. Properly designed signage and graphics shall enable passengers to find their way from origin to destination without asking station staff for directions.

Consistency – Signage and graphics are keys to system branding and in defining corporate identity. Signage and graphics shall identify system elements at stations, sites, and approaches.

Content, size, style, symbols, color, composition, and font shall be consistent. Standard pictograms shall convey information for passengers unable to read the corresponding text.

Placement – Signage shall be logically placed to optimize visibility.

Content – Other transportation systems and modes shall be integrated into the signage plan. Signage and graphics shall meet the requirements of ADA, CPUC, NFPA 130, and CFR Title 29, Part 1910.

Lighting – Where necessary for clarity and visibility whether day or night, signage shall be illuminated either internally or externally, as appropriate.

Sign Types – Station signage shall include the following:

- Directional signage – the key to wayfinding. Directional signage shall be placed at every potential decision point for passengers either entering or exiting the station.
- Informational signage
- Regulatory signage – exiting and other code-related signage
- Instructional signage – explains how passengers can use the HST System
- Warning and safety signage
- Maps of the HST System and other local intermodal transit systems, the neighborhood and vicinity
- Train Schedules
- Arrival and departure information boards – provided along major circulation routes, in the ticket sales area, at the ticket barrier, in the Free and Paid Areas and on the platforms. Train information monitors shall be provided in waiting areas and on the platforms.
- Room name signage – Room, area, and facility names shall be provided for these facilities including door signs to rooms.
- Station Name Identification – System and station identification signage shall be provided on the building exterior, at entrances, at the passenger information center, at ticket sales areas and on platforms.

Signage and Graphics Manual – Refer to the CHSTP Signage and Graphics Manual for additional detailed information.

14.3.9.3 Public Address (PA) System

A public address system shall be provided as an auditory means for station staff to announce train arrivals, delays, security concerns and other significant passenger information. Speakers shall be installed throughout the station, including exterior approaches. Speakers shall be mounted high enough to not be readily visible but low enough to ensure voice clarity. Announcements may be made by station staff from the SCR, TCF, Passenger Service Center or

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Platform Agent Booth (if provided). Refer to the *Communications* chapter of this design manual for additional information.

14.3.9.4 Information Monitors

Video monitors shall be located throughout the station public areas to provide visual information, announcements and messages regarding train schedules, delays, etc., in conjunction with the public address system information. Visual information may also include weather reports, commercial advertising or other. Monitors shall be wall or ceiling mounted, and located at Concourse Free and Paid Areas and platforms. Refer to the *Communications* chapter for additional information

14.3.9.5 Customer Service Agents

Personnel staffing the Customer Service Center, the Platform Agent Booth (if provided), or other roving staff shall offer face-to-face information to passengers when signage, public address systems, and monitors are not sufficient to address a passenger's questions or concern.

14.3.9.6 Advertising

Advertising provides system revenue as well as visual interest to passengers awaiting trains. A system-wide policy shall be developed to locate advertising in a consistent fashion where it shall not conflict with other station information. Sizes shall be standardized throughout the system.

14.3.10 Station Finish Materials

14.3.10.1 General Considerations

Station finish materials will significantly influence the public perception of the HST System and its quality. Because passengers, staff, and visitors will have direct contact with station finishes, proper selection is essential. Although finishes may vary between stations, the finishes shall conform to consistent standards of quality and aesthetics.

The following factors shall be considered when selecting station finish materials:

- **Safety –** Safety is the highest priority of the CHSTP. Interior station finish materials shall meet the fire resistive criteria of NFPA 101. Station construction materials shall also conform to the requirements of the 2010 CBC. Particular attention shall be given to the seismic design criteria for the attachment of finish materials. Finishes shall be selected to minimize potential hazard due to combustion or smoke generation.
- **Durability –** Finish materials shall be highly resistant to wear and accidental or malicious damage. The difficulties associated with replacing materials in a public transportation facility dictate the use of high quality and durable finishes that are easily maintained and that maintain their inherent qualities over time. Materials shall maintain quality for at least 30 years before replacement is necessary. Colors shall not change or fade.

- **Maintenance –** In addition to initial cost, life-cycle maintenance costs shall be considered in selection of materials and finishes. Finish materials shall be selected for ease of cleaning and inherent resistance to staining or soiling. Maintenance shall be carried out without the use of special equipment. Finish materials shall be selected and detailed with ease of repair or replacement.
- **Resistance to Vandalism –** Materials within reach of the public shall be graffiti resistant and cleanable without special techniques.
- **Appearance –** Timeless quality shall be conveyed by public area finish materials. Color and texture shall be harmonized throughout the building exterior and interior.
- **Color –** Floor material colors shall be integral. Surface-applied color treatments are not permitted. Color shall consider minimum contrast requirements for tactile paths and platform-edge materials. Colors shall be predominantly light to medium tones in order to maintain high and naturally efficient reflectance and illumination levels while concealing soil.
- **Texture –** Floor finish materials shall have minimum surface irregularities for ease of cleaning and to minimize collection of dust and dirt. Where slip resistance is essential, medium-rough texture may be acceptable.
- **Corrosion Resistance –** Metal finish materials in public areas shall be stainless steel or aluminum in non-public areas miscellaneous metals shall be galvanized and painted.
- **Review –** A materials color board shall be submitted to the Authority for review prior to specification.

14.3.10.2 Station Design Module

A station planning design module of 4 feet-0 inches shall be applied to station public areas for the purposes of economizing and standardizing material dimensions, integration, and replacement of system-wide elements, and minimization of custom cutting. Structural elements shall be spaced on consistent multiples of this module wherever possible. Finish materials may be subdivided into smaller modular units such as 2 feet-0 inches or 12 inches. This basic detail module shall apply to vertical and horizontal surfaces.

To the fullest extent practicable, joints and pattern lines in floor, walls, and ceilings shall be coordinated with building movement joints. Special attention is required for the detailing of multiple movement joints, which the long station structures will require. Finish material selections shall allow detailing of movement joints with minimal or no custom fabrications of joint covers, plates, etc.

14.3.10.3 Floors

Durability – Floors shall be subject to the highest degree of wear due to foot traffic, luggage, carts, etc. Durability is therefore a critical factor in material selection.

Slip Resistance – Floor materials shall be highly slip-resistant in public areas, including exterior entrance approaches, Concourses, stairs and landings, platforms, etc.

Tactile Routes – Inset tactile paths and platform edges for visually impaired passengers shall be considered in laying out floor-finish patterns.

Joints – Size of floor finishes shall consider minimizing the number and size of joints between units.

Construction – Most platform- and Concourse-area floor finishes shall be installed in setting beds over lightweight concrete fill slabs. The fill slabs shall provide for the installation of conduits and other mechanical, electrical and communications systems. Civil-structural dimensions shall allow adequate depth and width for embedded conduits and systems.

Access Panels – Floor panels for under-floor system access shall be coordinated with the finish floor patterns and modular dimensions.

Maintenance – In addition to previous maintenance requirements, floor finishes shall not be affected by the use of chemical cleaning materials.

Table 14-21: Acceptable Floor Finishes

Location	Finishes
Platforms	Smooth concrete (sealed); stone, tile, concrete
Concourse and Mezzanines	Smooth concrete (sealed); stone, tile, terrazzo, marble, recycled composite tile
Pedestrian walkways, bridges, and tunnels	Smooth concrete, stone, tile
Public service areas	Smooth concrete, stone, tile, sheet linoleum and related products, composition tile
Commercial spaces	Provided by tenants, in accordance with HST criteria and building code
Toilet Rooms	Smooth concrete (sealed), stone, tile, pavers, terrazzo, recycled composite tile
Non-public station staff areas	Smooth concrete (sealed or stained), tile
Equipment rooms	Smooth concrete (dust free) with hardener as appropriate, sheet linoleum and related products, composition tile
Storage rooms	Smooth concrete

14.3.10.4 Walls and Columns

Public Access – Wall surfaces within reach of the public, from the floor up to 8 feet-0 inches height, shall be hard, dense, non-porous, non-staining, and acid and alkali resistant for long life and low maintenance.

Transparency – Transparent walls and railings are desirable to bring daylight into stations, enable views, and facilitate passenger orientation within the station.

Elevators – In accordance with the elevator section of this chapter, interior elevators shall be predominantly glazed in accordance with building and elevator codes.

Installation – Where prefabricated finish panels are used, consideration of storage and installation of matching materials is essential. Simple access to concealed attachments shall be considered in the design of prefabricated panel finishes.

Acceptable interior wall and column finishes:

- Natural stone
- Precast concrete, smooth finish
- Exposed structural concrete (with stain-inhibiting finishes)
- Smooth cement plaster
- Ceramic tile, porcelain tile, recycled composite tile
- Laminated and tempered glass, transparent or opaque; glass-like materials
- Stainless steel
- Prefinished metal panels
- Gypsum board at non-public, low maintenance spaces

14.3.10.5 Ceilings

Integration – The preferred design approach integrates structural and architectural elements and minimizes the need for suspended ceiling solutions.

Coordination – Station ceiling design shall coordinate the station architecture with station support services, including mechanical, electrical, lighting, communications, station information, etc. Suspension of these elements shall be coordinated.

Seismic – Ceiling suspension systems shall meet or exceed seismic design criteria.

Module – Where suspended ceilings are used, the system shall be coordinated with the major station modules.

Access – Hinged or other fastening systems shall be included to allow access to concealed systems with a minimum of tools and equipment; rapid removal and replacement, cleaning, opening and closing shall be allowed.

Table 14-22: Acceptable Ceiling and Overhead Architectural Treatment

Platforms	Exposed Canopy Structure
Concourse and Mezzanines	Exposed structure with integrated daylighting; suspended metal panels, insulated perforated metal panels, cementitious sprayed acoustic materials
Pedestrian walkways, bridges, and tunnels	Exposed structure, with integrated daylighting where possible
Public station services areas	Exposed where appropriate or suspended modular systems with integrated lighting and HVAC systems
Commercial spaces	Provided by tenants, in accordance with HST criteria and building codes
Toilet Rooms	Suspended, impact and moisture resistant gypsum board with epoxy paint finish
Non-public station staff areas	Suspended gypsum board, painted, suspended acoustic tile systems
Equipment rooms	Exposed structure where appropriate; dust proof finish
Storage rooms	Exposed structure

14.3.10.6 Railings

Guardrails and barriers in station public areas may include clear laminated tempered glass with stainless steel supports and top rails, or stainless steel picket type. Refer to Standard and Directive Drawings. Railings in non-public areas may be galvanized and painted steel.

14.3.10.7 Station Exterior

General – This section provides guidance for the selection of exterior materials for station buildings, including platform areas and pedestrian bridges, walkways and tunnels. General considerations described previously apply to exterior as well as interior finish materials.

Roofs – Stations are likely to be prominent structures in most locations. Individual station designs may have roof surfaces that are visible from ground level or may use a single material that serves as both roof and wall. In these cases, metal roofing systems may be appropriate. In urban areas, roofs may be visible from existing or future high-rise development. For highly visible roofs, a singular material, such as metal or a membrane system, is preferred.

In accordance with the Authority’s policy for sustainable design, roof materials with high petroleum content or proprietary systems are the least preferred types.

The long, linear platform canopy structures shall be assemblies of prefinished materials requiring little or no maintenance over the course of their design life.

All station roofs shall be provided with roof drains. Gutters, rain leaders, and grade-level connections into the station roof and walls shall be integrated into roofs and walls.

Exterior Walls – Acceptable exterior wall materials include concrete and precast concrete panels, natural stone, porcelain enamel steel, stainless steel prefinished steel, and aluminum panel systems.

Glass is a desirable material for station exterior walls to provide daylight and promote a sense of openness and security. Energy considerations require that appropriate shading be included with east-, south-, and west-facing glass walls. Convenient glass-cleaning strategies shall also be considered.

Where the track level is below grade, exposed concrete and masonry—including stone, tile, and composite concrete materials—are appropriate.

Where platforms are elevated, large areas of platform enclosures may be architectural fence materials or metal and glass weather screens. Common wall areas shall be transparent to allow views, daylight, and security between station interiors and platforms.

14.3.11 Security Provisions

14.3.11.1 Objectives

The primary goal of station security is to protect the station passengers and staff, the facilities, and the train systems.

To achieve this goal, in addition to operational provisions, prudent passive station planning techniques shall be employed, including open, unobstructed lines of sight, avoidance of potential hiding places, and use of CCTV where direct surveillance is not possible.

14.3.11.2 Security Facilities

Primary station security facilities include a Security Office and a Police Office. Secondary station security provisions include the SCR, TCF, the Station Manager's Office and the Platform Agent Booth at designated Terminal Stations. Refer to Section 14.3.6 for facility requirements.

Space shall be allowed between the free and Paid Areas where active security measures may be installed. Refer to Section 14.3.3.5 for space requirements.

14.3.11.3 Security Devices and Alarms

Non-public and building system spaces shall be secured with a system-wide electronic locking system and intrusion alarms. Station entrance doors and gates shall be equipped with audible alarms connected to the Security Office and the SCR. Design criteria for doors, gates, and locking mechanisms required for the prevention of unauthorized access to emergency exits, rooms with fixed equipment, corridors, stairwells and other controlled areas may be found in the Operations and Maintenance Plans. Security devices shall be provided at each station area as shown in Table 14-23.

14.3.11.4 Station Closure

The station shall be able to be fully closed and secured during the daily schedule and in case of emergency. Security gates shall be used to close the station during non-revenue hours. Security gates can be key-controlled from both the inside and the outside of the station. Each station entrance shall have at least one main door for use by staff to exit when the station is closed and the security gate is closed.

Table 14-23: Security Devices in Stations

Station Area	Security Devices and Provisions				
	CCTV	Sensing Device	Emergency Button	Intercom	Increased Lighting
Area open to the public during system operating hours					
Station Entrance	X	X			X
Free Area	X			X	
Ticket Sales Area	X			X	X
Ticket Gates	X			X	X
Paid Area	X			X	
Public Stairs	X				X
Escalators	X				X
Elevators	X			X	X
Platform	X		X	X	X (at edge)
Public Restrooms	X (at entrance)		X		X (at entrance)
Area open to staff at all times and to the public during emergency or special circumstances					
Station Operation Office Entrances	X	X			
Emergency Stairs	X	X		X	
Controlled Access for staff only					
Cash Handling/Ticket Storage	X	X			
SCR	X	X			
Station Computer Room		X			
Building Service/Core System Room Entrances		X			
End of Platform		X			

14.4 Station Site Design

14.4.1 Site Design Objectives

Station sites shall incorporate Authority's facilities as described in this chapter while achieving the following fundamental site design objectives:

- Optimize multimodal access between the station and other potential transportation modes.
- Facilitate simple, direct, and safe movement of people and vehicles to, from, and within the site. Site design shall contribute to passenger convenience by:
  - Facilitating clear, safe and direct intermodal connectivity;
  - Clearly identifying public station facilities from public rights-of-way; and
  - Minimizing conflicts between modes.
- Promote connectivity to existing and planned pedestrian, bicycle, transit and street networks.
- Orient station facilities to the surrounding community in a pedestrian-friendly, accessible and sustainable manner.
- Coordinate site facilities and site design with local jurisdictions and regional transit providers to ensure a site layout that supports the CHSTP's objectives, as well as local government and regional transit provider objectives and requirements.
- Ensure emergency access to stations, including statutory fire lanes and vehicle access.
- Ensure system-wide consistency in site design.

14.4.2 Access Hierarchy

14.4.2.1 Planning Principles

A hierarchy of access modes to and from HST stations will help to ensure safe and efficient service to HST patrons and to resolve potential conflicts between modes. Station sites shall include the following:

- Promote efficiency of person trip access to HST stations
- Ensure multimodal balance of station area access
- Ensure safe multimodal access

The following modes of access are listed from highest to lowest priority.

- Rail-to-rail transfers (HST, Amtrak and/or commuter)
- Pedestrians (walk trips to and from the station)
- Transit, including bus, van, carpool, taxi etc.

- Bicycles
- Drop-Off and Pick Up
- Automobile Parking

14.4.2.2 Rail

Where HST station sites connect with other rail services, passenger transfer between HSTs and other rail services shall be as seamless and convenient as possible. Walking distances and the number of required vertical level changes shall be minimized.

Integration of HST and other rail services at a single station facility is preferable for passenger convenience and orientation. Where rail stations are separated by necessity, they shall be located as close as possible to each other. Visual connections to connecting system platforms shall be provided where possible. Connecting pedestrian walkways shall be designed to be obvious and intuitive.

14.4.2.3 Pedestrians

A. Pedestrian Principles

Pedestrian access shall be afforded the highest priority of access. Guidelines for pedestrian movement are as follows:

- Pedestrian routes shall be simple, comfortable, direct, well lit, visually unobstructed and along or visible from public streets. Pedestrians will seek the shortest route and the site plan shall anticipate this behavior.
- Pedestrian routes shall be contiguous and separated from motorized vehicles wherever practicable. Pedestrian conflicts with other travel modes are to be avoided.
- Pedestrian routes shall connect the station entrances, transit services, passenger drop-off, parking, adjacent rights-of-way and other station-area facilities.
- Pedestrian routes shall connect the station area and station entrance to key intersections and pedestrian routes adjacent to the site in order to provide ease of pedestrian access to and from off-site destinations.
- Pedestrian access and circulation shall address actual and perceived potential security concerns.
- Pedestrian routes shall avoid unnecessary turns or dead-ends, routes through parking lots, and isolated or hidden segments.
- All elements shall conform to accessibility guidelines. Accessible routes shall connect all public site facilities and destinations. Site furniture and stairs shall be located outside of this route.
- Pedestrian flow shall be designed for right-hand flows where practical.

- Existing and planned pedestrian and bicycle routes shall be considered within a minimum 1/2 mile of the station when designing routes on the station site.

B. <u>Pedestrian Walkways and Sidewalks</u>

Pedestrian walkways and sidewalks shall provide for the majority of pedestrian circulation. Guidelines are as follows:

- Steps or abrupt changes in level shall be minimized.
- Layout of pedestrian walkways shall provide maximum visibility of and by oncoming vehicular traffic. Routing pedestrian walkways adjacent to columns or walls that reduce pedestrian visibility to vehicle operators shall be avoided.
- Where pedestrian-vehicle interfaces are unavoidable, crosswalks and pathways shall be marked and clearly visible to motorists. Finish, contrasting color, or other elements of design to differentiate pedestrian paths and crossings and increase patron safety and security shall be used.
- Sidewalks are required next to stations or other structures when vehicle circulation or parking is adjacent to the building.
- Provision of canopies for weather protection is encouraged along pedestrian transfer walkways or other exterior high pedestrian traffic areas.

C. <u>Pedestrian Bridges and Underpasses</u>

Where street-level pedestrian walkways cannot be provided, elevated pedestrian bridges may be necessary. Bridges shall be provided with protective screens and continuous kick plates to prevent objects from being dropped or kicked from the bridge.

Where underpasses or tunnels are required, design shall prioritize patron security including shortest practical length, ample width, bright lighting, and security monitoring.

Where grade changes are greater than allowable ramp slopes, provide stairs, escalators, or elevators in accordance with Section 14.3.4.

14.4.2.4 Intermodal Transfer

At the station site, facilities are required to allow access and boarding and alighting of other modes of transit. Non-HST passenger volumes shall be estimated and used to determine the appropriate sizes and configuration of pedestrian circulation facilities within the station site.

Maximum walking distance to the station entrance from a transit boarding or alighting area shall be 500 feet. Where possible, transit facilities shall be visible from the station, arterial streets and nearby activity areas. At-grade pedestrian crossings of vehicle lanes shall be minimized.

Facilities for transit vehicles—including access, circulation, boarding, and alighting areas—shall be separated from other traffic where practicable.

Waiting areas at transit loading areas—sized according to peak period demand at a pedestrian LOS B or better—shall be provided

A. Bus

Planning – Bus facilities shall provide for safe and accessible bus boarding and alighting while providing an efficient operating space for bus routes. Bus facilities are assumed to remain active and busy throughout the day, and vacant, underutilized space during off-peak periods shall be avoided. Where feasible, the site shall be designed to accommodate future bus service growth.

Bus Waiting – Weather protection or shelter the length of the bus platform shall be provided with a canopy that extends to cover bus doorways. Boarding zones shall be provided with lighting, seating, and service information. Light poles, bollards, fire hydrants, and other site furniture shall be located at least 4 feet from the curb edge.

Station Site Access – Bus facilities shall be located on the site with easy access from major bus routes to reduce out-of-direction travel. Where possible, buses shall be segregated from other traffic entering the facility. When exclusive right-of-way is not available, controlled access may facilitate free movement of transit vehicles in and out of the station. Controlled access ranges from a protected left-turn lane out of the station to exclusive bus right-of-way entry and circulation within the station site.

Bus Facility Geometry – Bus bays may be designed as sawtooth bus bays or tangent bus bays. Minimum dimensions for each are dictated by local codes. Sawtooth bays are generally preferable because they require less curb space than tangent bays. In no situation shall bus bay geometry require backing (as in angled or diagonal bays). Bus lanes shall have a minimum width of 12 feet (or as dictated by local codes) and shall be configured to allow buses to pass each other. Bus facilities shall be planned for one-way operations with right-hand drop-off/pick-up directly onto bus waiting areas and corresponding pedestrian paths. For additional bus planning criteria, refer to the *Civil* chapter.

Layovers – For routes that terminate at the station, the operator will need to “layover” either on station property or on the street adjacent to the station. If layovers occur at the station, layover parking shall be located to reduce recirculation needed to re-enter service and corresponding congestion. At least 1 bus bay or other bus parking space shall be provided for each route that will layover. Multiple bays are required if the scheduled headway is less than or equal to the layover duration.

B. Intercity Bus

Facilities for intercity buses shall be provided on a station-by-station basis, depending on existing facilities in the surrounding community and estimated potential future demand in that community for intercity bus service.

Design standards and guidelines shall follow intracity bus guidelines.

C. Driver Relief Station/Restrooms

Where requested by bus companies, driver's restroom facilities shall be provided on site for use by specific transit agencies. Determination of this need may be made based on the level of transit service provided at the station and local transit operational plans by the Authority with the input of local transit agencies. These facilities shall not be open to the general public.

14.4.2.5 Bicycles

HST Travel – Bicycles shall be allowed on trains and therefore access to and from station entrances shall accommodate bicycles. Bicyclists will be permitted to pass through accessible Fare Gates.

Circulation Routes – Where practicable, bicycle circulation shall be segregated from vehicle and pedestrian flows through the provision of bicycle-only paths direct to the station. In most cases, however, bicycles will need to make the most effective use of roadways and curb cuts. If bicycle routes are shared with roadways, bicycle lanes shall be designated.

Storage – Bicycle racks and lockers shall be provided at station sites. The amount of bicycle storage will vary based on demand, which depends on surrounding land uses, terrain, bicycle facilities. and other factors. Bicycle parking shall be located as close to the station entrance as practicable given site constraints and other design guidelines. Where practicable, bicycle parking shall be within sight of station staff and general station pedestrian traffic for surveillance. From the bicycle parking area, it shall be easy to access the station entrance and the surrounding bike network and street system. The area shall be covered, well-lit, secure, and highly visible.

Sharing – In addition to bicycle storage racks and lockers, space shall be provided for bicycle-sharing pick-up and return facilities at appropriate stations.

14.4.2.6 Pick-Up and Drop-Off Zone

A. Planning Principles

Passenger pick-up and drop-off zones will be used by multiple modes, including private automobile kiss-and-ride, taxi, paratransit, private shuttle buses, and rental cars.

Planning shall encourage vehicle turnover, reduce conflicts, and facilitate traffic flow. This zone shall be close to the station entrance. Convenient recirculation of vehicles within the station site shall be provided where feasible in order to reduce congestion on the road network surrounding the site.

Pedestrian routes between the station entrance and vehicle drop-off area shall be direct with no vehicle lanes to cross. Walking distance from this area to the station entrance shall be less than 600 feet. Lane widths shall allow vehicles to pass those who are stopped. This zone shall be separated from kiss-and-ride facilities and located to avoid interference with transit operations. Access roads for kiss-and-ride facilities may be shared provided operation of either facility is not interrupted. However, pick-up/drop-off traffic shall not be routed through parking facilities.

Right-hand drop-off, pick-up, and recirculation shall be provided without leaving the station site in order to reduce congestion on surrounding streets.

Depending on the demand for pick-up and drop-off facilities, some station sites may segregate the two uses by having a pick-up area and a drop-off area. If the curb length required to service demand exceeds station frontage by 200 percent, then separate arriving and departing areas with a loading island in front of building will be necessary.

At stations with high demand for pick-up and drop-off, it may be appropriate to provide a waiting area for automobiles outside of the pick-up and drop-off zone so that automobiles are not waiting at the curb for the train to arrive (and therefore blocking other patrons' access) or circulating, which results in increased congestion.

B. Private Shuttle / Van

Shuttle van access may be located in the pick-up and drop-off area. Shuttle vans include private paratransit, parking shuttles, hotel shuttles, and other services. Separation from other modes depends on demand.

C. Kiss and Ride

Passenger kiss-and-ride areas are set aside for private automobile drivers to pick-up and drop-off HST customers. Design of these areas shall consider the following:

- Stalls and aisles for passenger drop-off areas shall be larger than those in long-term parking areas due to the frequent turnover, as indicated in the *Civil* chapter.
- Preferred parking arrangements for passenger drop-off areas are as follows (in order of preference):
  - Parallel to curb
  - 45 degrees to the drive aisle
  - 60 degrees to the drive aisle
  - 90 degrees to the drive aisle
- Pedestrian crosswalks shall leave a minimum of 20-foot zones on either side of parallel parking stalls, or greater if directed by local codes.
- If drop-off areas are provided in a park-and-ride lot, placement shall avoid conflicts with entering and exiting traffic.

For additional kiss-and-ride planning criteria refer to *Civil* chapter.

D. Rental Car

Rental car drop-off or pick-up service may be integrated into the kiss-and-ride area. Scale of facilities varies by demand and Authority's policy.

E. <u>Taxi</u>

The number of passengers arriving by taxi will determine the operational characteristics of the taxi areas. Once taxi activity passes a threshold level of operations, taxis begin to interrupt other pick-up/drop-off area operations. Further increases in taxi activities may require segregation of taxi pick-up and drop-off areas. Design of taxi facilities shall follow the following guidelines based on magnitude of taxi activity:

- Low – Taxi operations mix with shuttle vans and kiss-and-ride.
- Medium – Taxi operations are segregated from other modes of arrival. Taxi operations may be mixed with other modes if pick-up and drop-off areas are segregated.
- High – Taxi operations are segregated from other modes of arrival; further segregation of taxi pick-up and drop-off areas

Stalls or pick-up/drop-off areas shall be marked according to whether the stalls are "Taxi Only" or shared with other pick-up/drop-off modes. Space shall be provided for taxi queuing or corralling prior to pick-up of arriving HST patrons. The queuing space size shall correspond to projected waiting taxi demand, and it shall be located near to, but not at the taxi pick-up area in order to provide quick service but not interfere with operations at the station entrance. Where analysis indicates significant potential demand for taxi service and passenger queuing at the taxi pick-up location, a staffed taxi dispatcher booth or desk may be required.

14.4.2.7 Parking

A. <u>Planning Principles</u>

Parking may be designated as short term, all day, or long term. Local zoning regulations shall be met or exceeded. The following standards ensure adequate access and performance of parking facilities:

- Parking areas located outside of station sites shall be connected to station entrances by pedestrian walkways, bridges, or underpass structures by pedestrian walkways conforming to the requirements of this section.
- On-site parking shall be provided within easy walking distance to the station entrance. The maximum walking distance for any parking space from the station entrance shall be 1,500 feet or a 7-minute walk.
- For stations where adequate on-site parking cannot be provided adjacent to the station or within a short walking distance, off-site facilities may be developed, which shall be served by parking shuttle services.
- Connections between parking areas and station entrances shall be direct and obvious. Parking shall be designed so that those leaving their cars are "fed" onto primary pedestrian routes.
- Parking facilities shall be located as close as possible to the streets serving the site.

- Parking shall be at 90-degree angles with two-way aisles and no dead ends.
- Pedestrian movements within parking areas will normally occur along drive aisles. Where possible, drive aisles shall be oriented towards the station to facilitate pedestrian flow and to minimize the need to walk between parked cars.
- Striped pedestrian walkways may also be required where pedestrians flow perpendicular to aisles.
- Speed bumps may be considered to reduce vehicle speeds for pedestrian safety.
- Configure parking to allow station access for emergency vehicles including fire equipment and ambulances.

For additional parking criteria, including dimensional layout for station site area parking, refer to the *Civil* chapter.

B. Multi-level Parking Structures

Parking structures are not anticipated to be included inside station area plans. However, parking structures provided for the use of patrons shall conform to HST parking requirements.

Parking structures shall conform to the following standards:

- Parking structure siting shall not create conflicts between pedestrian circulation to stations and the surrounding community. Driveways that serve parking shall avoid crossing main pedestrian routes in the station area.
- Parking structures shall be oriented to minimize the walking distance between the station entrances and automobiles.
- Parking structures shall be sized and located to encourage shared use of parking.
- Where possible, the street level of parking structures shall incorporate active uses to increase natural surveillance and a sense of pedestrian activity.
- Parking structures and station entrances shall be connected with continuous, accessible, covered pedestrian walkways.

For additional multi-level parking structure criteria, refer to the *Civil* chapter.

C. Motorcycle Parking

Motorcycle/scooter parking stalls shall be provided as part of station parking. Local codes shall be considered in facility design. Motorcycle stalls may be preferably located in leftover space that would otherwise not be used. Stall sizes shall be consistent with Standard and Directive Drawings. Motorcycle parking shall not be allowed at station entrances, in bicycle parking area, on sidewalks, or other pedestrian walkways.

D. Carpool/Vanpool Parking

Where appropriate, reserved parking stalls shall be provided for people who arrive at the station in vanpools and carpools. Initial planning and environmental assessment for the facility shall identify potential need for these stalls. If implemented, the stalls shall be located closer to the station entrance than general parking. Local requirements shall be considered in design.

E. Car-Sharing/Station Car Parking

Where appropriate, reserved parking stalls for car-sharing vehicles (i.e., ZipCar, CityCarShare, etc.) vehicles shall be provided. Initial planning and environmental assessment for the facility shall identify potential need for these stalls. If implemented, the stalls shall be located closer to the station entrance than general parking. Local requirements shall be considered in design.

F. Accessible Parking Requirements

In accordance with requirements of ADA and state building code, accessible parking shall be provided at facilities where parking is provided. ADA parking shall be located closest to the station entrance with a direct, accessible path leading to the station entrance. For additional accessible parking criteria, refer to the *Civil* chapter.

G. Staff Parking

Parking stalls shall be provided, which are consistent with staff functional needs, yet do not pre-empt convenient passenger parking. Staff parking shall be located and identified so that station patrons do not use employee spaces.

H. Security Parking

Parking stalls shall be provided for the use of HST security or police personnel. Spaces shall be located close to the station entrance. Security parking shall be identified so that station patrons do not use these spaces.

I. Passenger Pick-Up (“Cell Phone”) Parking

Where appropriate, parking shall be provided for people picking up HST passengers while they wait for trains to arrive. Passenger pick-up parking does not need to be located adjacent to stations but pick-up and drop-off zones shall be easily accessible from this parking area. Amenities, such as real-time train arrival information, shall be considered.

J. Electric Vehicle Charging Stations

Where appropriate, electric vehicle charging stations shall be provided in station parking facilities. Electrical requirements for electric vehicle charging stations are provided in the *Facility Power and Lighting Systems* chapter.

K. Parking Management System

Because parking will be provided at market rates, control at access and egress points is necessary. Parking facilities shall be designed to allow for queuing for pay-on-entry or pay-on-exit systems. The number of entrance and exit lanes will vary by demand, but at least 2 lanes in each direction are required in the case of maintenance or a stalled vehicle at 1 gate. Traffic loop

sensors, traffic gates, and antennas shall be provided in order to implement gate cashiering, “pay on foot,” Smart Card, conventional multi-space meter, or other revenue collection systems.

14.4.3 Vehicle Access and Circulation

14.4.3.1 Planning Principles

Vehicle access to the station site shall not interfere with access modes of higher priority. The location and design of vehicle entrances and exits shall take into account the following factors:

- Primary station site vehicular access shall be located along higher capacity streets (such as arterial streets), to provide direct connections to local destinations and to protect adjacent neighborhoods from excessive vehicle congestion.
- Access via high-speed arterials shall be avoided.
- Curb cuts shall be minimized.
- Access roadways shall be planned with sufficient traffic storage capacity to meet expected patronage at peak times and to prevent traffic backing up onto public streets.
- The number of access roads shall be limited to reduce confusion and increase efficiency. Intersections shall allow traffic to flow at LOS D or better (Highway Capacity Manual).
- Access points shall be located to reduce crossing movements for inbound traffic (on the right side of the roadway) where possible.
- Exclusive turn lanes shall be provided only where necessary to maintain acceptable traffic operations.

14.4.3.2 Service and Maintenance Vehicle Access

All station sites shall have a loading zone and parking spaces with special access routes separate from other traffic provided for delivery trucks, service trucks, refuse trucks and other maintenance vehicles. Designated access route for cash-handling vehicles to cash-handling facilities shall be considered. Loading and unloading zones for delivery trucks shall be located to avoid interruption of station operations. An access route shall be considered for installation or future replacement of station equipment and facilities.

14.4.3.3 Emergency Access

Access for emergency response by fire department and paramedic equipment/personnel shall be provided, consistent with local codes. Fire lanes shall be clearly marked on the pavement. Refer to Section 14.3.1.4 for additional emergency access information.

14.4.4 Roadways

Standards and guidelines for roadways are as follows:

- Street and intersection dimensions shall be planned to facilitate pedestrian and vehicular movement.

- Roadways shall circulate counter-clockwise and be configured to allow for recirculation within the site, allowing passengers to drop off a passenger and then park or retrieve a car from the parking area and then pick up an arriving passenger at the station curb.
- One-way traffic operation shall be provided if adequate right-of-way is available.
- In order to control speeds, roadways shall be no wider than necessary for "design" travel speeds and emergency vehicle access and egress.
- On-street parking shall be considered in order to slow traffic and buffer pedestrians.
- Roadways intended to provide access to bus zones, park-and-ride stalls, and passenger drop-off areas shall be designed in accordance with the *Civil* chapter and local transit provider design guidelines.
- Provisions for passing a stalled vehicle shall be made along roadways exiting from public streets.
- Where there are main sidewalks and crosswalks, there shall be no wide-turning radii, driveways, garage entrances or dedicated turning lanes that require pedestrian refuge islands.

For additional roadway criteria refer to *Civil* chapter.

14.4.5 Site Infrastructure

14.4.5.1 Site Utilities

- Sitework design at stations shall include investigation of existing utilities for relocation or removal as required.
- Locations of major tree installations shall be identified in time to coordinate with necessary underground utilities.
- Utility design criteria are included in the *Utilities* chapter.

14.4.5.2 Site Grading and Drainage

- Paved and planter surfaces shall conform to the existing prevailing site topography and slope towards site drains.
- Site surfaces shall be sloped away from buildings and sheet flowing onto paved passenger circulation routes leading to station entries shall be avoided.
- Sites shall be sloped in a way that minimizes the potential for water infiltration at points of pedestrian access to stations.
- Rain leaders from roofs shall be connected to underground drainage conduits. Splash blocks and surface outlets on paved pedestrian areas shall not be permitted.
- Site drainage criteria are included in the *Drainage* chapter.
- Grading criteria are included in the *Geotechnical* chapter.

14.4.5.3 Site Lighting

Purpose – Site areas shall be well lighted. The purposes of site lighting include providing for passenger safety, to aid with wayfinding and to ensure clarity and visibility throughout the site.

Source – Site lighting sources shall be coordinated with adjacent street lighting to provide the same or similar quality of light. Site pedestrian walkways, sidewalks, parking areas, bus shelters, etc. shall use metal halide or conforming high pressure sodium sources unless noted otherwise.

Poles – Mount site lighting on medium to low aluminum poles on round concrete bases adjacent to pedestrian walkways or in planters within parking areas.

Light Spill – Care shall be taken to prevent site lighting from spilling onto adjacent properties. Light shields may be used to direct site lighting towards the intended areas.

Plantings – Care shall be taken to prevent plantings from interfering with essential site lighting and signage.

Lighted Signage – Directional, informational and regulatory signage shall be clearly illuminated to permit visibility throughout the site.

Exterior Building Lighting – Coordinate with station lighting as indicated in Section 14.3.7.

Facility lighting criteria is described in detail in the *Facility Power and Lighting Systems* chapter.

14.4.5.4 Site Signage

Site signage information may be found in Section 14.3.9 - Information Systems.

14.4.5.5 Site Security

Station site security infrastructure includes the following:

- CCTV cameras
- Emergency intercoms
- Customer assistance intercoms
- Station area lighting
- Access control system
- Intrusion detection system
- Signs indicating emergency procedures
- Fire truck access lanes and signs

14.4.5.6 Finish Materials

Refer to Section 14.5 - Landscaping for site hardscape, paving and retaining wall materials.

14.4.5.7 Architectural Fencing and Gates

- Architectural fences and gates in public areas of the station site are described in this section. Utilitarian chain-link fencing shall not be used in public station plaza areas.
- Architectural fences and gates for individual stations shall be compatible with station architecture.
- Preferred materials for fencing materials are stainless steel, painted galvanized steel, or powder coated steel.

14.4.5.8 Site Furnishings

In addition to site criteria mentioned previously, the following site furnishings shall be provided as appropriate, including but not limited to the following:

- Benches and individual outdoor seating
- Bus and taxi queue shelters – Where passengers connect to other transportation modes at stations, shelters shall provide comfortable waiting areas, with appropriate shade and weather protection and wayfinding provisions. Additional information may be found in Section 14.4.4 Intermodal Transfers.
- Security phones, alarms and related accessories
- Flagpoles
- Waste receptacles
- Bollards (as needed to prevent unauthorized vehicle entry) – These shall be removable and if necessary for emergency or maintenance vehicle access, securable with a padlock.
- Public phones

Site furnishings shall be designed with respect to design life, durability, weather resistance, maintainability, vandalism resistance as well as attractive appearance and functionality for patrons.

14.4.5.9 Station Plaza

An entry plaza shall be planned to demarcate a gateway to the station and a place for pedestrians to congregate. Size and design will vary by site.

14.4.5.10 Communication and Electrical Buildings

If additional communication or electrical buildings are required on the station site away from the station, the buildings shall be co-located with service vehicle parking. Also, ancillary buildings shall be located in close proximity to HST tracks and away from general vehicle circulation. As a security measure, communications and electrical buildings shall be located away from passenger areas and not be identified with signage.

14.5 Landscaping

14.5.1 Scope

Landscaping criteria describe planting, hardscape, and irrigation for individual HST station sites, support facilities, line sections, trackways, portals, and wayside structures and repair of existing landscaping.

Erosion Control – Erosion control at stations, other facilities, and along the alignment shall follow standards in the Caltrans Highway Design Manual and Erosion Control Technical Guide.

Planting – Criteria is included for selection of new plant materials, paving, and site furniture as well as replacement and maintenance of existing plant materials.

Irrigation – Criteria are included for modification of existing irrigation systems and for the design of efficient irrigation systems for new planting.

14.5.2 General Landscaping Principles

Goals – Facilities will be situated within a wide diversity of microclimates, temperatures, humidity, soil conditions, air quality, and visual contexts. Therefore, the facility landscaping shall be designed and selected to be appropriate for each individual site in lieu of a system-wide landscaping approach.

Consistent system-wide landscaping goals include the following:

- The materials and mass of structures shall be softened through addition of plantings, water features, artwork, or other passenger-friendly site amenities that respond to the individual site microclimates and physical site contexts.
- The passenger and visitor experience, while entering or departing the station, shall be enhanced.
- Passenger circulation routes outside stations shall be defined.
- Shade shall be created and excessive heat gain shall be reduced in front of station entries; windbreaks and shelters shall be provided from precipitation where appropriate.
- Existing station area urban design concepts, site-specific historic landmarks, and natural features and views shall be related.

Site Circulation – Landscape features shall contribute to the clarity of the passenger circulation path from the site perimeter to the station entries. Landscape features shall not obstruct direct pedestrian routes to and from the station entrances.

Entry Plaza – Stations shall provide at least one entry plaza at or near grade level, where the major opportunities for tree size planters will be located. The need for shading structure in the

station plaza area may rely on a mix of semi-mature trees and fabricated structures to moderate the large amounts of hard surfaces at elevated station plazas.

Safety – Trees, planters, and site furnishings shall not obstruct lines of sight for passengers and station staff nor create potential hiding areas.

Maintenance at Stations – New plant materials shall be selected for compatibility with local microclimates, resistance to pests, moderate or low irrigation requirements, and integration with any existing planting to remain. Planting areas shall be designed to minimize maintenance costs and potential for theft or vandalism.

Maintenance of landscaping requires control or prevention of the growth of plant materials inside the facility perimeter. Plant materials that may be used for screening of the facilities shall avoid migration past the facility perimeter.

Utility Coordination – New planting areas shall be coordinated with existing and planned station area underground and overhead utilities. Locations of deep tree wells with underground utilities shall be coordinated.

Grounding Coordination – Landscaping design shall be coordinated with ground grid locations to avoid conflicts between tree roots and grounding, in accordance with the *Grounding and Bonding Requirements* chapter.

14.5.3 Facility Types

14.5.3.1 Elevated Stations

Upper Levels – Opportunities for introduction of plant materials on upper levels at elevated stations will be limited by programmatic, operational, maintenance, and structural conditions.

Planters – Where above-grade raised or recessed planters are contemplated, structural loads, waterproofing, irrigation, drainage, and routine maintenance access shall be addressed.

14.5.3.2 At-Grade Stations

Plantings – At-grade stations offer opportunities to bring landscape planting areas close to the station. The use of trees native to the station site will aid in connecting the station to the surrounding urban context. If there are other street tree species used near the station plaza area, they may be appropriate to use for neighborhood continuity.

14.5.3.3 Rights-of-Way – Trackways

General Policy – Ornamental landscape planting along trackway shall not be permitted within the Authority's right-of-way except with approval by the Authority. Only drought-resistant ground cover requiring minimal maintenance shall be approved along trackways. Hardscape features such as retaining walls and terraces may be used, in addition to plant materials, to maintain slopes along trackways.

Special trackway planting may be approved in urban areas, where train speeds will be low, and along tracks approaching stations. Native and locally proven plant materials are encouraged. Trackway planting at stations shall be coordinated with the overall station area landscape design concept.

Special trackway landscape is permitted only in areas with roadway vehicle access; however, landscape maintenance is not permitted in areas used by maintenance-of-way track vehicles.

Slope stabilization, erosion, and dust control during construction are addressed by Caltrans Standards.

Setbacks – Minimum distance between track centerline and any landscape and tree planting is addressed in the *Trackway Clearances* chapter.

Maintenance – Refer to the Operations and Maintenance Plan for additional information about maintenance of landscaping within the Authority's right-of-way. Maintenance and irrigation requirements shall not interfere with train operations.

14.5.3.4 Tunnel Portals

Objective – Landscaping around tunnel portal sites includes mitigation of trees and other natural features that will be permanently altered by portal construction. Solutions that carefully contrast natural features with made-made portal features are more successful and enduring and require less maintenance.

Plantings – Plant material selection shall be limited to surrounding existing species.

Tunnel Facilities – Larger portal area facilities such as power substations, communications equipment rooms, ventilation equipment rooms and maintenance storage rooms may be partially recessed into portal structures with planted roof areas using native vegetation. Access roads, maintenance storage yards, vehicle parking areas, and emergency response staging areas may create graded or paved flat areas in previously sloped terrain. Cuts and fills shall be treated to prevent erosion and planted for compatibility with surrounding topography and existing vegetation.

14.5.3.5 Support Facilities

Scope – See the *Support Facilities* chapter for a detailed description.

Urban Context – Support facilities located in urban areas may require dense landscape screening and architectural walls. Use of selected trees and shrubs for screening may be appropriate.

Wayside Facilities – Landscaping at wayside facilities along the Authority's right-of-way shall be low maintenance. Perimeters around equipment shall be surrounded with concrete, precast paving blocks, dense gravel, ballast rock, etc.

Screen Walls – Where wayside facilities occur in urban areas, partial screen walls of masonry or ornamental metal fabrications may be appropriate.

14.5.4 Plant Materials

14.5.4.1 New Plant Materials

Planting Areas – General planting requirements include the following:

- Select attractive planting that enhances the building design and site area.
- Select drought-resistant and locally-native planting within the site area.
- Limit planted slopes to 2:1
- Minimize site maintenance through the use of drought-resistant plantings.
- Avoid the need for extensive irrigation systems or maintenance such a lawns or plant materials that shed large amounts of leaves or fruits.

Drought Resistance – In accordance with Authority's policies for sustainable design goals, 75 percent of new plant materials shall be drought resistant, requiring very low irrigation. Where practicable, native plant materials requiring minimal irrigation shall be selected as a regional solution to station area planning and landscaping.

Clear Zones – Plantings within public utility corridors that parallel, cross, or intersect the Authority's facilities shall be coordinated. Additional criteria for protection and maintenance of the respective underground, surface, or overhead infrastructure shall be coordinated with vegetation that is proposed for stations and facilities.

A. <u>Plant Size</u>

Plantings shall be installed in accordance with the following minimum sizes:

• Ground Cover:	1 gallon
• Shrubs:	1 and 5 gallons
• Perimeter Trees:	15 gallons
• Circulation Trees:	15 gallons
• Pedestrian Walkway and Plaza Trees:	24-inch box
• Parking Area Trees:	24-inch box

B. <u>Tree Selection</u>

The major tree types to be used at stations and other facilities include the following:

- **Parking Areas –** Large deciduous trees. Paved parking areas shall be softened with tree planters at intervals of approximately one tree per ten parking spaces.

- **Pedestrian Walkways and Station Plazas –** Medium-size flowering deciduous trees. Pedestrian area trees may also be combined with raised seating planters of stone or concrete. Topsoil in planters shall be planted with ground covering.
- **Perimeter Trees –** Extensions of existing street tree planting patterns of the surrounding station area site. The interface of perimeter trees with the station area site plan shall be coordinated with local urban design standards or guidelines.

C. Green Roofs

Use of green roof planting may be considered for stations.

14.5.4.2 Existing Plant Materials

Site Survey – Station and other facility sites with significant existing planting that will be impacted by construction shall be surveyed by a landscape architect registered in the State of California. Trees and shrubs shall be documented for protection in place, relocation, removal, temporary removal, or replacement.

Existing Trees – Where local communities have significant, established urban features such as uniform street tree planting, consideration shall be given to extending the theme into the station area site plan.

Sustainability – Landscape design for stations shall conform to the Authority's sustainability goals. If existing local street tree and landscape area planting requires significant irrigation, points shall be identified on the site perimeter where appropriate transitions may be made between the existing high water use plantings and the sustainable plantings.

Exceptions can be made where significant existing trees or landscaped park may have important local historic value. Where such features may become a part of the new station area site plan, the responsibility for ongoing maintenance shall be clearly defined.

Where sites require temporary clearing and restoration of wider project rights-of-way, and if the project requires replacement of existing plant materials, designers shall take the opportunity to introduce more sustainable plant materials into the landscape restoration with the permission of the local jurisdiction.

14.5.5 Irrigation

Efficiency – Landscape irrigation shall be planned to provide efficient water use. Plantings that are not drought tolerant shall be irrigated separately from the remaining plantings.

Budget – Station or support facility landscape plans shall begin with clear limits on quantities of available irrigation water on an annual basis. Plant material selection shall be limited to species that can thrive on the available irrigation budget.

Collection – Stormwater systems shall be designed to capture rainfall into street gardens and bio-swales. Wherever possible, non-potable water suitable for landscape irrigation shall be used.

Grey Water – If local municipalities have established gray water infrastructure in place at station sites, wastewater may be treated on site to local sanitary district specifications and discharged into the local gray water system.

14.5.6 Hardscape

14.5.6.1 Paving

This section addresses general landscape criteria for paved areas for vehicles, bikes, pedestrians, service vehicles, and buses in both public and non-public areas. Further design criteria site work paving is included in *Civil* chapter.

Paved pedestrian areas shall conform to requirements in the 2010 CBC and ADAAG.

Roadways shall be separated from pedestrian walkways by 6-inch-high curbs, where curbs are appropriate considering drainage.

Pedestrian area paving materials shall be concrete, precast, or stone pavers. Asphalt paving in pedestrian areas is permitted only as a temporary repair.

Appearance, life cycle cost, and recycling shall be considered when selecting paving materials. In order to support the CHSTP's sustainability goals, locally produced materials shall be used wherever practicable.

Tree Grates. Pedestrian area trees shall be set in tree grates and pruned to allow approximately 8 feet of clearance below horizontal branching. Grates shall be a minimum of 4 feet x 4 feet with a hole pattern in conformance with ADA standards.

14.5.6.2 Pedestrian Walkways

Pedestrian walkway paving materials shall contrast in appearance from vehicle paving materials.

Pedestrian walkways shall be constructed of materials approved for pedestrian area paving. Pedestrian walkways shall conform to relevant accessibility design requirements of the 2010 CBC and other local requirements.

Manholes, grates, drain covers, underground utility access covers, and related site structures shall not be located in pedestrian walkways unless absolutely necessary.

Sloped grades, less than 5 percent are preferred to ramps along pedestrian walkways.

For additional pedestrian walkway standards within the Station Area Site Design, refer to Section 14.4.3.2.

14.5.6.3 Landscape Retaining Walls

Landscaping retaining walls higher than 4 feet-0 inches are described in the *Structures* chapter. Retaining walls for paving and landscape elevation changes shall be stepped or terraced.

Materials for retaining walls shall be poured-in-place, reinforced concrete, precast concrete, reinforced unit masonry, or modular cut stone.

Retaining walls shall have appropriate internal drainage to prevent excessive collection of moisture. Outlets shall not drain onto paved pedestrian walkways.

Chapter 15

Support Facilities

HSR 13-06 - EXECUTION VERSION

Revision	Date	Description
0	02 Mar 12	Initial Release, R0

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Acronyms

ADA	Americans with Disabilities Act
CHST	*Not Used; use HST for California High-Speed Train*
CHSTP	California High-Speed Train Project
HMF	Heavy Maintenance Facility
HST	High-Speed Train
HVAC	Heating, Ventilation, and Air Conditioning
LOS	Level of Service
MOI	Maintenance of Infrastructure
OCC	Operations Control Center
OCS	Overhead Contact System
RCC	Regional Control Center
TSMF	Terminal Storage and Maintenance Facilities

15 Support Facilities

15.1 Scope

This chapter provides architectural and planning design criteria for California High-Speed Train (HST) support facilities.

15.2 Regulations, Codes, Standards, and Guidelines

Refer to the *General* chapter for requirements pertaining to regulations, codes, and standards. This chapter presents design standards and guidelines specifically for the construction and operation of HST support facilities based on international best practices and applicable state and federal requirements.

Since support facilities will be located in multiple municipal jurisdictions, other transportation owner/operators' rights-of-way, and/or unincorporated jurisdictions, the CHSTP standards and guidelines may differ from local jurisdictions' codes and standards.

Applicable codes, rules, standards, and guidelines include but are not limited to the following:

- Code of Federal Regulations (CFR) Title 28, Part 36 – Nondiscrimination on the Basis of Disability by Public Accommodations and in Commercial Facilities
- California Building Code (CBC), Title 24 of California Code of Regulations (CCR)
- Americans with Disabilities Act (ADA)
  - ADA Standards for Accessible Design
  - Guidance on the ADA Standards for Accessible Design
  - ADA Accessibility Guidelines (ADAAG)
- National Fire Protection Association (NFPA)
  - NFPA 101 – NFPA's Life Safety Code
  - NFPA 130 – Standard for Fixed Guideway Transit and Passenger Rail Systems
- American National Standards Institute (ANSI) 117.1 – standard for accessible design for persons with disabilities
- California Division of the State Architect California Access Compliance Reference Manual

15.3 Support Facilities

This section describes architectural requirements of the non-station buildings and related facilities to accommodate all activities necessary for the maintenance, operation, and administration of the HST System.

Support Facilities include the following:

- Heavy Maintenance Facility
- Operations Control Center
- Regional Control Centers (2)
- Terminal Storage and Maintenance Facilities (4)
- Heavy Maintenance Facility
- Administrative Headquarters Building
- Maintenance-of-Infrastructure (MOI) and Rolling Stock Maintenance (RSM) Facilities (7)
- Portal Facilities
- Mid-tunnel Ventilation Structures
- Emergency Access Shafts
- Line Facilities including the following:
  - Traction Power, Switching, and Paralleling Stations
  - Train Control / Communications and Control Wayside Structures and Cabinets
  - Trackside Systems Equipment

15.3.1 Design Principles

- **Design Quality** – Support Facilities shall be designed to exhibit the Project's commitment to excellent design for all types of facilities, exhibiting architectural and functional solutions appropriate to the context in which they are built.
- **Life Cycle** – Materials, assemblies, construction techniques, products, and systems shall be selected for durability, appearance and cost-effectiveness with a design life of 50 years. While many components of the facilities may be replaced in shorter periods of time, all design decisions shall maintain this long-range view.
- **Structural Design** – Structural design elements of Support Facilities shall conform to the requirements described in the *Structures* chapter.
- **Grounding and Bonding –** Service siding platform design shall be coordinated with the requirements specified in the *Grounding and Bonding Requirements* chapter.

15.3.2 Heavy Maintenance Facility

Purpose – High-speed train sets shall be assembled, tested, and commissioned at the Heavy Maintenance Facility (HMF). During revenue service, periodic major maintenance shall be performed at the HMF, as well as unplanned maintenance and repairs. The HMF shall also provide overnight storage of a portion of the train fleet. Along with the Operations Control Center (OCC), the daily functioning of the HST System may be co-located at the HMF.

Building Functions – Refer to Table 15-1 and the Operations and Maintenance Plan for detailed descriptions of functional requirements for the HMF.

The major shop buildings at the HMF shall accommodate 2 full length single-train sets of approximately 700 feet each. They shall accommodate light and heavy industrial processes to completely maintain and repair all components of the high-speed vehicles. The vehicle servicing layout, daylight illumination, and natural ventilation functions of these buildings will influence the architectural design.

Table 15-1: Heavy Maintenance Facility Space Requirements

Function	Minimum Area Required
Enclosed Inspection Tracks	X s.f.
Exterior Train Washing	X s.f.
Automated Wheel Inspection	X s.f.
Wheel truing/re-profiling	X s.f
Heavy duty interior cleaning platform(s)	X s.f.
Toilet Servicing	X s.f.
Inspection “pit” tracks	X s.f.
Traction Power Inspection and Maintenance	X s.f.
Pantograph Inspection and Maintenance	X s.f.
Sanding System Replenishment	X s.f.
Detailed Bogie Inspection and Maintenance	X s.f.
Train Exterior Workshop	X s.f.
Electric Components Inspection and Maintenance	X s.f.
Machining Tool Facility	X s.f.
Parts receiving, storage, and distribution	X s.f.
Administrative, training, and staff supports areas	X s.f.
Operations Control Center	X s.f.

Access – HMF roads shall provide efficient circulation and parking for administrative, maintenance, receiving, and operations staff vehicles and private cars. HMF roads shall also allow access to emergency vehicles and controlled access for delivery of maintenance parts and

supplies. The site plan shall also include an appropriate public approach to the administration component of the facility for visitors.

Sustainability – In accordance with the Project's sustainability goals and commitment to 100 percent renewable energy sources, photovoltaic, wind, and other alternative energy harvesting infrastructure shall be included in the design of the HMF.

HMF Gate House – The HMF main entry shall be controlled by security personnel in a gatehouse with facilities and equipment to monitor pedestrians and vehicle access on a 24-hour schedule. Personnel at the gatehouse shall monitor arriving and departing vehicles, including staff private vehicles, materials suppliers, visitors, and emergency vehicles.

Exterior – As the first building that all visitors will encounter on the site, the gatehouse shall be an architecturally attractive facility, coordinated with the concept and expressions of the main HMF shop buildings. Weather protection shall be provided over the driver section of entering vehicles and vehicle barriers and curbs to protect the building and staff. Security lighting shall be provided to monitor gate and site access.

Interior – The gatehouse shall incorporate systems to monitor and remotely operate all perimeter gates at the HMF site. The gatehouse shall include a space for guard operations as well as a compact kitchen, lockers, and a uni-sex toilet room, heating, ventilation, and air conditioning (HVAC) system and interior lighting.

15.3.3 Operations Control Center

Purpose – The OCC provides a secure location for Operations staff to supervise and control the HST System 24 hours per day, year-round. Refer to Table 15-2 and the Operations and Maintenance Plan for a complete description of the components and functions of the OCC.

Table 15-2: Operations Control Center Space Requirements

Function	Minimum Area Required
Control Center Operating Theater	X s.f.
Server Room	X s.f.
Incident Room	X s.f.
Conference Room	X s.f.
Manager Office	X s.f.
Staff Break Room/Kitchenette	X s.f.
Private Staff Offices (8)	X s.f. each
Staff Lockers and Restrooms	X s.f.
Administrative, training, and staff support areas	X s.f.
Equipment Rooms	X s.f.
Reception/Waiting Room	X s.f.

Location – The OCC may be a freestanding building or co-located with the HMF. Considering the significant functional differences between the OCC and the HMF Administrative offices, these functions may be located separately from the shop buildings, in a freestanding building. If freestanding, it shall be on a secure location within the HMF site. The OCC shall be expandable to house the full build-out operations.

There is no requirement for direct connection between the OCC and the HMF facilities or staff.

Functions – Major activities within the OCC include the following:

- Train dispatching and control
- Supervisory Control and Data Acquisition (SCADA)
- Infrastructure control, monitoring and maintenance
- Monitoring of fire and life safety systems
- Communications and passenger information
- Fleet Management
- Manpower Management
- Emergency response and management
- System Security
- Traction Power Control and Operation

Building Features – OCC facility requirements include the following:

- Secure, controlled entry
- Internal security points
- Emergency backup power
- HVAC systems
- Controllable daylight
- Dedicated emergency response workstations.

Shared Facilities – If the OCC is co-located with the HMF, the OCC operation may share some staffing and operational functions with the administrative requirements of the HMF. Spaces such as entry lobbies, security check points, break rooms, training rooms, and lockers may be shared.

The equipment located in a Server Room shall be located directly adjacent to the Control Center Operating Theater. The Control and Server Rooms shall have a depressed floor structure with computer flooring.

15.3.4 Headquarters Building

Purpose – The headquarters building shall be the official administrative center of the HST System.

Phasing – During the initial Phase 1 planning, design, and construction, the administrative offices may be located in temporary space. As staffing needs grow and administrative program becomes more fully defined, the Authority may require a dedicated Administration Building.

Location – In order to support the Authority's stated policies for station development to "encourage high-density development in and around the HST stations" the Administration Building shall be located with the same goal.

Design Goals – The headquarters building will be a high-profile facility and shall exemplify the Authority's high goals for design excellence. In accordance with design guidelines for stations, the Authority supports the California Division of State Architect, Department of General Services "Excellence in Public Buildings" program, which promotes "high-performing public buildings and a positive architectural legacy that reflects the State's commitment to excellence."

Sustainability – In addition to high quality design, cost effectiveness, universal accessibility, and other requirements, the headquarters building shall achieve Leadership in Energy and Environmental Design Silver certification.

Function – The design of the headquarters building will require integration of modern administrative offices, conference and meeting spaces, public relations functions and related support spaces, within the context of a large historic rail yard context.

Refer to Table 15-3 for a preliminary space-planning program for the Headquarters Building.

Table 15-3: Headquarters Building Space Requirements *(to be further developed)*

Function	Minimum Area Required
Main Lobby	X s.f.
Executive Offices (4)	X s.f.
Conference Rooms (2)	X s.f.
Conference Rooms, Small (2)	X s.f.
Administrative Offices	X s.f.
Training Rooms	X s.f.
Staff Offices	X s.f.
Others *TBD*	X s.f.

15.3.5 Terminal Storage and Maintenance Facilities

Purpose – Routine servicing, inspection, and light-to-intermediate maintenance of the trains shall occur at the Terminal Storage and Maintenance Facilities (TSMF), which provide overnight, scheduled maintenance, inspection, and storage and morning start-up of revenue services. Refer to Table 15-4 and the Operations and Maintenance Plan for detailed planning information.

Table 15-4: Terminal Storage and Maintenance Facilities Space Requirements

Function	Minimum Area Required
Entrance/Assembly Shop	X s.f.
Enclosed Inspection Tracks	X s.f.
Exterior Train Washing	X s.f.
Automated Wheel Inspection	X s.f.
Wheel truing/re-profiling	X s.f
Heavy duty interior cleaning platform(s)	X s.f.
Toilet Servicing	X s.f.
Inspection "pit" tracks	X s.f.
Traction Power Inspection and Maintenance	X s.f.
Sanding System Replenishment	X s.f.
Parts receiving, storage, and distribution	X s.f.
Administrative, training, and staff support areas	X s.f.

Function – The primary functions to be accommodated within the TSMF include the following:

- Overnight storage of trainsets
- Periodic inspection (San Francisco and Los Angeles)
- Quick replacement of running gear, underbody, and pantograph parts
- Train washing and Interior cleaning
- Commissary provisioning

Type of Building – The maintenance facilities associated with the TSMFs can be considered smaller versions of the HMFs. In contrast to the HMFs, most of these TSMFs will be located within urban areas. Some TSMFs will be highly visible and in close proximity to industrial, commercial and residential land uses. Although the TSMF buildings will house different maintenance functions, the scale, massing, and proportions shall follow the same design principles as those stated for the HMF.

Gate House – The TSMF main entry shall be controlled by security personnel in a gate house with facilities and equipment to monitor pedestrians and vehicle access similar to the HMF gate house.

15.3.6 Regional Control Centers

Purpose – On the Caltrain and Los Angeles to San Diego shared-use corridors, multiple carriers currently maintain complex joint operations that, independent of HST, are expected to become progressively more so. As a result, the CHSTP Command & Control system is proposed to be designed to include a Northern California Regional Control Center (RCC) and Southern California RCC that will focus exclusively on regional operations on these busy corridors on a 24-hour/7-days-a-week basis. Refer to Table 15-5 and the Operations and Maintenance Plan for a complete description of the components and functions of the RCCs.

Table 15-5: Regional Control Center Space Requirements

Function	Minimum Area Required
Control Center Operating Theater	X s.f.
Server Room	X s.f.
Incident Room	X s.f.
Conference Room	X s.f.
Manager Office	X s.f.
Staff Break Room/Kitchenette	X s.f.
Private Staff Offices (8)	X s.f. each
Staff Lockers and Restrooms	X s.f.
Administrative, training, and staff support areas	X s.f.
Equipment Rooms	X s.f.
Reception/Waiting Room	X s.f.

Location – RCCs are proposed to be located at the Level 3 TSMF situated near San Francisco and Los Angeles. The RCCs may be freestanding buildings or co-located with the TSMF. The RCCs shall be expandable to house the full build-out operations.

There is no requirement for direct connection between the RCCs and the TSMF facilities or staff.

Functions – Major activities within the RCCs include the following:

- Train dispatching and control
- SCADA
- Infrastructure control, monitoring and maintenance
- Monitoring of fire and life safety systems

- Communications and passenger information
- Fleet Management
- Manpower Management
- Emergency response and management
- System Security

Building Features – RCC facility requirements include the following:

- Secure, controlled entry
- Internal security points
- Emergency backup power
- HVAC systems
- Controllable daylight
- Dedicated emergency response workstations.

Shared Facilities – If the RCC is co-located with the TSMF, the RCC operation may share some staffing and operational functions with the administrative requirements of the TSMF. Spaces such as entry lobbies, security check points, break rooms, training rooms, and lockers may be shared.

The equipment located in a Server Room shall be located directly adjacent to the Control Center Operation Room. The Control and Server Rooms shall have depressed floor structure with computer flooring.

15.3.7 Line Facilities

Type – Several types of facilities are required along the length of the HST system at various intervals.

- Traction Power Facilities (see the *Traction Power Supply System* chapter)
- Maintenance of Infrastructure Facilities
- Wayside Facilities

Maintenance of Infrastructure Facilities – MOI facilities are required at regular intervals (distance to be determined) along the Authority's right-of-way. These facilities shall maintain the track, Right-of-Way, Overhead Contact System (OCS) systems, and related wayside equipment during the nighttime period of non-operation, using non-OCS powered vehicles. Size – 24-26 acres with two buildings approximately 30,000 square feet each.

Where space and site conditions permit, MOI facilities may be co-located with the HMF or 4 TSMF.

Wayside Facilities includes various equipment cabinets, OCS equipment, cable and conduit access boxes, radio transmission facilities, and related communication and control equipment installed along the Authority's right-of-way.

MOI design shall be coordinated with the requirements specified in the *Grounding and Bonding Requirements* chapter.

15.4 Support Facilities Site Design

15.4.1 Site Design Objectives

Support Facility sites shall achieve the following fundamental site design objectives:

- Facilitate simple, direct and safe movement of people and vehicles to, from, and within the site.
- Ensure emergency access to support facilities including statutory fire lanes and vehicle access.
- Ensure system-wide consistency in site design.

15.4.2 Parking

Parking may be designated as short term (visitor) or long term. Local zoning regulations shall be met or exceeded. The following standards ensure adequate access and performance of parking facilities:

- On-site parking shall be provided within easy walking distance to the support facility entrance.
- Parking shall not necessitate crossing of maintenance tracks to reach the facility entrance.
- For support facilities where adequate on-site parking cannot be provided adjacent to the facility or within a short walking distance, off-site facilities may be developed that are served by parking shuttle services.
- Parking facilities shall be located as close as possible to the streets serving the site.
- Parking shall be configured to allow station access for emergency vehicles, including fire equipment and ambulances.

For additional parking criteria, including dimensional layout for station site area parking, refer to the *Civil* chapter.

15.4.3 Vehicle Access and Circulation

15.4.3.1 Planning Principles

The location and design of vehicle entrances and exits shall take into account the following factors:

- Primary site vehicular access shall be located along higher capacity streets (such as arterial streets), providing direct connections to local destinations and protecting adjacent neighborhoods from excessive vehicle congestion.
- Access via high-speed arterials shall be avoided.
- Access roadways shall be planned with sufficient traffic storage capacity to meet expected flow at worker shift times and to prevent traffic backing up onto public streets.
- The number of access roads shall be limited to reduce confusion and increase efficiency. Intersections shall allow traffic to flow at Level of Service (LOS) D or better (Highway Capacity Manual).
- Access points shall be located to reduce crossing movements for inbound traffic (on the right-side of the roadway) where possible.
- Exclusive turn lanes shall be provided only where necessary to maintain acceptable traffic operations.

15.4.3.2 Service and Maintenance Vehicle Access

All support facility sites shall provide a loading zone and parking spaces with special access routes separate from other traffic provided for delivery trucks, service trucks, refuse trucks, and other maintenance vehicles. Loading and unloading zones for delivery trucks shall be located to avoid interruption of facility operations.

15.4.3.3 Emergency Access

Access for emergency response by fire department and paramedic equipment/personnel shall be provided consistent with local codes. Fire lanes shall be clearly marked on the pavement.

15.4.4 Roadways

Roadways providing access to parking, bus zones, and staff drop-off areas shall be designed in accordance with the *Civil* chapter and local transit provider design guidelines.

15.4.5 Site Infrastructure

15.4.5.1 Site Utilities

- Sitework design at support facilities shall include investigation of existing utilities for relocation or removal as required.
- Locations of major tree installations shall be identified in time to coordinate with necessary underground utilities.

- Utility design criteria are included in the *Utilities* chapter.

15.4.5.2 Site Grading and Drainage

- Paved and planter surfaces shall conform to the existing prevailing site topography and slope towards site drains.
- Site surfaces shall be sloped away from buildings and shall avoid sheet flowing onto paved pedestrian circulation routes.
- Rain water leaders from roofs shall be connected to underground drainage conduits. Splash blocks and surface outlets on paved pedestrian areas are not permitted.
- Site drainage criteria are included in the *Drainage* chapter.
- Grading criteria are included in the *Geotechnical* chapter.

15.4.5.3 Site Lighting

Purpose – Site areas shall be well-lighted. The purposes of site lighting include providing for worker and visitor safety, to aid with wayfinding, and to ensure clarity and visibility throughout the site.

Source – Site lighting sources shall be coordinated with adjacent street lighting to provide the same or similar quality of light. Site pedestrian walkways, sidewalks, parking areas, bus shelters, etc. shall use metal halide or conforming high-pressure sodium sources unless noted otherwise.

Poles – Site lighting shall be mounted on medium to low aluminum poles on round concrete bases adjacent to pedestrian walkways or in planters within parking areas.

Light Spill – Care shall be taken to prevent site lighting from spilling onto adjacent properties. Light shields may be used to direct site lighting towards the intended areas.

Plantings – Care shall be taken to prevent plantings from interfering with essential site lighting and signage.

Lighted Signage – Directional, informational, and regulatory signage shall be clearly illuminated to permit visibility throughout the site.

Exterior Building Lighting – Station lighting shall be coordinated as indicated in the *Stations* chapter.

Facility lighting criteria is described in detail in the *Facility Power and Lighting Systems* chapter.

15.4.5.4 Site Signage

Site signage shall conform to standardized project signage and graphics established for the CHSTP. System signage information is described in the *Stations* chapter.

15.4.5.5 Site Security

Station site security infrastructure includes the following:

- Closed Circuit Television (CCTV) cameras
- Emergency intercoms
- Station area lighting
- Access control system
- Intrusion detection system
- Signs indicating emergency procedures
- Fire truck access lanes and signs

15.4.6 Landscaping

Scope – See the *Stations* chapter for a detailed description of landscaping requirements.

Urban Context – Support facilities located in urban areas may require dense landscape screening and architectural walls. Use of selected trees and shrubs for screening may be appropriate.

Wayside Facilities – Landscaping at wayside facilities along the Authority's right-of-way shall be low maintenance. Perimeters around equipment shall be surrounded with concrete, precast paving blocks, dense gravel, ballast rock, etc.

Screen Walls – Where wayside facilities occur in urban areas, partial screen walls of masonry or ornamental metal fabrications may be appropriate.

Chapter 16

Mechanical

HSR 13-06 - EXECUTION VERSION

Revision	Date	Description
0	02 Mar 12	Initial Release, R0

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Figures

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Acronyms

16 Mechanical (TBD)

TBD. This topic will be included in a future revision of the Design Criteria.

Chapter 17

Facility Power and Lighting Systems

HSR 13-06 - EXECUTION VERSION

Revision	Date	Description
0	02 Mar 12	Initial Release, R0

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Acronyms

ANSI	American National Standards Institute
ATC	Automatic Train Control
Authority	California High-Speed Rail Authority
BAS	Building Automation System
CBC	California Building Code
CEC	California Electric Code
CHSTP	California High-Speed Train Project
EMT	Electrical metallic tubing
EWLCP	Emergency Walkway Lighting Control Panel
FAA	Federal Aviation Administration
FPS	Facility Power System
GFCI	Ground-Fault Circuit Interrupters
GRS	Galvanized Rigid Steel
HV	High Voltage
HVAC	Heating, Ventilation and Air Conditioning
I/O	Input/Output
IEEE	Institute of Electrical and Electronic Engineers
IESNA	Illuminating Engineering Society of North America
LCP	Local Control Panel
LS	Lighting System
LV	Low Voltage
MOI	Maintenance of Infrastructure
NEC	National Electric Code
NEMA	National Electrical Manufacturers Association
NFPA	National Fire Protection Association
O/RCC	Operations/Regional Control Center
OCS	Overhead Contact System
PVC	Polyvinyl chloride
SCADA	Supervisory Control and Data Acquisition
TES	Traction Electrification System
TVM	Ticket Vending Machine
UPS	Uninterruptable Power Supply

17 Facility Power and Lighting Systems

17.1 Scope

This chapter provides design criteria of Facility Power and Lighting Systems for the various trackside facilities and trackside equipment. The specified requirements apply to the entire California High-Speed Train Project (CHSTP).

The design requirements and criteria for these systems to be installed for the CHSTP address the following:

- Classifications of Electrical Loads
- General Requirements (Operational, Functional, Performance)
- General Design Standards and Codes of Practice
- Supply Voltage
- Electric Utility Services
- Emergency Power Supply Systems
- Sustainable Power Sources
- Facility Power System Equipment
- Specialized Electrical Equipment
- Facility Lighting
- Specialized Lighting
- Raceway Systems
- Wiring/Cabling Systems
- Identification Requirements for Electrical Infrastructure
- Supervisory Control and Data Acquisition (SCADA) and/or Building Automation System (BAS) requirements

The design requirements and criteria specified herein shall be coordinated with the requirements specified elsewhere in the Design Criteria and Contract Documents.

The criteria have been established to provide the basis to complete the design. The responsibility for the design integrity, as well as integration and coordination with other disciplines remains with the designer.

17.2 Regulations, Codes Standards, and Guidelines

Refer to the *General* chapter for requirements pertaining to regulations, codes, and standards.

- California Code of Regulations (CCR)
  - Title 8 – Occupational Safety and Health Act Standards
  - Title 19 – Public Safety
  - Title 24 – Parts 1, 2, 3, 6 and 9
- California Public Utility Commission (CPUC) General Orders (GOs)
  - CPUC GO 95 – Rules For Overhead Electric Line Construction
  - CPUC GO 128 – Construction of Underground Electric Supply and Communications Systems
- California Building Code (CBC)
- California Electric Code (CEC)
- American Concrete Institute (ACI) Standards
- American Institute of Steel Construction (AISC)
- American National Standards Institute (ANSI) Standards
  - ANSI C2 – National Electrical Safety Code (NESC)
  - ANSI Z535.1 – Safety Color Code
  - ANSI Z535.3 – Criteria For Safety Symbols
  - ANSI Z535.4 – Product Safety Signs and Labels
- American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc (ASHRAE) Standards
- Illuminating Engineering Society of North America (IESNA) Standards
  - Lighting Handbook Reference and Application
  - RP-20, Lighting for Parking Facilities
  - RP-22, Tunnel Lighting
  - TM-11, Light Trespass: Research, Results, and Recommendations
- Institute of Electrical and Electronic Engineers (IEEE) Standards
  - IEEE 141 – Recommended Practice for Electrical Power Distribution for Industrial Plants
  - IEEE 142 – Recommended Practice for Grounding of Industrial and Commercial Power Systems
  - IEEE 241 – Recommended Practice for Electrical Power Service in Commercial Buildings

- IEEE 242 – Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems
- IEEE 383 – Standard for Qualifying Class 1E Electric Cables and Field Splices for Nuclear Power Generating Stations
- IEEE 399 – Recommended Practice for Industrial and Commercial Power System Analysis
- IEEE446 – Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications
- IEEE 493 – Recommended Practice for Design of Reliable Industrial and Commercial Power Systems
- IEEE 519 – Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems
- IEEE 693 – Recommended Practices for Seismic Design of Substations
- IEEE 1100 – Recommended Practice for Powering and Grounding Sensitive Electronic Equipment
- IEEE 1584 – EEE Guide for Performing Arc Flash Hazard Calculations
- IEEE C37.010 – Application Guide for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

- National Fire Protection Association (NFPA) Codes and Standards
  - NFPA 70 – National Electric Code (NEC)
  - NFPA 70E – Standard for Electrical Safety in the Workplace
  - NFPA 101 – Life Safety Code
  - NFPA 110 – Standard for Emergency and Standby Power Systems
  - NFPA 111 – Standard on Stored Electrical Energy Emergency and Standby Power Systems
  - NFPA 130 – Standard for Fixed Guideway Transit and Passenger Rail Systems

New electrical utility services to CHSTP facilities and trackside equipment enclosures shall comply with the design standards of the applicable electric utility service provider. Refer to the *Utilities* chapter for additional requirements.

17.3 Description of the Facility Power System

The Facility Power System (FPS) comprises all of the equipment, cables, raceway systems, mounting hardware and appurtenances required to isolate, transform, distribute and/or

disconnect the power source(s) to the facility equipment and Core Systems (e.g., system-wide communications, train control) where these are co-located within, or adjacent to, a facility.

The design of the FPS shall incorporate features to account for single point of failures and ensure the availability of power to the connected electrical loads. The design of the FPS shall include the following:

- Normal power source
- Backup power source and/or
- Emergency power supply source

The normal and backup power sources can originate from the local electric utility service provider and/or the Traction Electrification System (TES). Each power source shall be sized for the connected electrical load (including prescribed spare capacity). During normal operations, the normal power source shall provide power to all of the connected electrical loads. During contingency operations, where the normal power source is no longer available, the connected electrical loads shall be automatically switched to the backup power source.

The emergency power supply sources are incorporated into the design of the FPS to provide additional power when normal and backup power (where provided) sources fail. An emergency power supply source can originate from the following:

- Emergency standby generator.
- Uninterruptable Power Supply (UPS) (typically provided for vital functions, e.g., train control, system-wide communications, or emergency lighting for compliance with California Building Code requirement and where interruptions cannot be tolerated)
- DC battery system

Where a permanent emergency standby generator is not provided at a facility, a generator receptacle shall be included in the FPS design to permit connection of a portable generator.

The UPS equipment shall be electrically connected to the permanent emergency standby generator 480 V ac bus (or generator receptacle where the former is not provided) and the normal/backup 480 V ac bus.

The following bus designations shall apply to the design of the FPS:

- Normal Bus – fed from the normal and/or backup power source.
- Generator Bus – fed from the emergency standby generator.
- Emergency Bus – fed from the UPS equipment (assigned to lighting only) or dc battery system.

- Essential Bus – fed from the UPS equipment (assigned to train control, system-wide communications, etc.).

The following list summarizes the minimum power sources to be provided at key facilities and/or trackside equipment enclosures:

- Passenger Station – normal, backup and emergency power supply sources
- Maintenance-of-Equipment Facilities (i.e., Heavy Maintenance Facility, Terminal Layup/Storage and Maintenance Facility) – normal, backup, and emergency power supply sources, with the facility power substation configured as double ended
- Maintenance-of-Infrastructure – normal, backup, and emergency power supply sources
- Portal Facility – normal, backup, and emergency power supply sources
- Tunnel – normal, backup, and emergency power supply sources [1]
- Mid Tunnel Ventilation Structure – normal, backup, and emergency power supply sources
- Emergency Access Shaft – normal, backup, and emergency power supply sources
- Sump Pump – normal and backup power sources
- Viaduct/aerial structure [2]
- Train Control/Communication Equipment Rooms (within Facilities) – normal and backup or emergency power supply sources [1]

Alternative power source arrangements may be submitted as a Design Variance Request to the California High-Speed Rail Authority (Authority) for review and approval.

Refer to the Traction Power Supply System, Automatic Train Control, Yard Signaling and Communication chapters for the design criteria associated with LV power distribution system at standalone pre-engineered buildings and\or remote trackside equipment.

17.4 Classifications of Electrical Loads

Electrical loads connected to the FPS shall be classified as follows:

[1] Provide a generator receptacle (at each tunnel) where the tunnel length is less than 2500'-0" and is located within 2 hours drive of a maintenance facility. A permanent generator shall be provided at a tunnel a)where the tunnel length exceeds 2500'-0", b) that is located in remote areas and can be accessed within 2 hours drive of the local maintenance facility, and c) comprising of a series of short length tunnels (back to back but spaced apart) where the combined length exceeds 2500'-0"

[2] Where a viaduct/aerial structure section is between tunnel sections the trackside facility power infrastructure can be routed between tunnels via the aerial-structure for convenience (subject to the Designer's overall FPS design).

- **Critical** – Load that cannot tolerate any interruption longer than 0.25 cycles, or that it must be maintained for some time after normal and backup power is lost and consequently shall be served by a UPS or battery-based (ac) power system. Critical loads include, but are not limited to, the following:
  - Alarm, supervision systems, and control power for operation of the FPS equipment, including medium-voltage and LV switchgear
  - Emergency lighting in passenger stations, tunnels, emergency egress, illuminated signs and maintenance and service facilities
  - Exits signs, variable message signs
  - Fire protection system and public address systems
  - Control power for emergency ventilation system
  - Control power for the TES
  - Control power for emergency communication system, and security systems
  - Control power for load shed panel
  - Normal electrical power for automatic train control systems
  - Normal electrical power for system-wide communication systems
  - Emergency electrical power for the functions at the Operations Control Center
  - Audio visual equipment for emergency exit stairs at areas of refuge
  - Power to field equipment needed for life safety systems
- **Essential** – Loads that can tolerate an interruption for the time required for a transfer switch or circuit breaker to operate. Such loads shall be backed up by an automatic transfer to an alternative power source and shall not be disconnected. Essential loads include, but are not limited to, the following:
  - Elevators
  - Tunnel lighting normal power source
  - Emergency ventilation fans and dampers
  - Station duplex sump pumps
  - Tunnel duplex sump pumps
  - Fare collection system
  - Normal power supply of the UPS systems
  - Battery charger
  - Heating ventilation, and air conditioning (HVAC) infrastructure at rooms that house equipment associated with the TES, Train Control System, and Communication System.

- **<u>Nonessential</u>** – Includes all loads not classified essential or critical. Such loads may not be backed up by an automatic primary transfer to an alternative power source and may be disconnected if necessary during emergency conditions. Nonessential loads include, but are not limited to, the following:
  - Normal lighting
  - Escalators
  - Station roll-up grille
  - Tenant/concessionaire spaces
  - Equipment or other subsystems not required for evacuation or security surveillance
  - General purpose and convenience receptacles at stations and along tunnels

17.5 General Requirements

17.5.1 Safety Design

The FPS design shall incorporate the following as a minimum:

- Avoiding, eliminating, or reducing hazards identified by engineering analysis, design choices, material selection, or substitution.
- Controlling and minimizing hazards (to personnel, the public, and to equipment and materials) that cannot be avoided or eliminated.
- Incorporating fail-safe principles where failures would disable the system or cause human injury, damage to equipment, or inadvertent operation of critical equipment.
- Locating equipment components so that access to them by the required personnel during operation, maintenance, repair, or adjustment shall not require exposure to hazards such as entrapment, chemical burns, electrical shock, cutting edges, sharp points, or toxic atmospheres.
- Providing suitable warning and caution notes in operations, assembly, maintenance, and repair instructions; and distinctive markings on hazardous components, equipment, or facilities for personnel protection.
- Venting components containing or generating obnoxious, flammable, and harmful gases to the outside.
- Physically segregating/separating cables and wires of different systems and, high voltage (HV) and LV conductors from each other in accordance with the requirements specified in the NEC and CEC.
- The following safety considerations shall be included in the design:

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- Overcurrent elements that are (i) designed to protect conductors serving emergency equipment, emergency lighting, Facilities Communication Systems and fire detection system; and (ii) located in spaces other than electrical rooms, shall not depend upon thermal properties for operation.
- Arc flash hazard warning labels shall be provided on all equipment, along with flash boundary, and incident energy values shall be provided in accordance with the NEC and CEC.
- Ground fault protection shall be provided on branch circuits that have equipment or receptacles for which personnel protection is required by the NEC, CEC, and engineering judgment.

17.5.2 Uniformity

Equipment enclosures, assemblies, sub-assemblies, and components that do not differ in operational, functional, or performance characteristics shall be designed so that all components are positioned in the same location and internal wiring is routed in between components in a like manner.

Where identical installations exist, the following requirements shall be adhered to:

- Unless site conditions prevent it, equipment enclosures shall be mounted and installed in a like manner.
- Penetrations for conduit, grounding, and access panels shall be located in the same place.
- The location of equipment relative to adjacent equipment shall not differ.
- The routing of conduit, tray, and cables between equipment enclosures shall not differ.
- Termination hardware shall be located in like manner.
- Cables and wire terminations shall be located in like manner.

Standardization:

- Equipment providing like functions shall be of the same design and manufacture.
- Equipment or devices of the same rating and function shall be identical and interchangeable.

17.5.3 Reliability, Availability, Maintainability and Safety

The design of the FPS and Lighting System (LS) shall ensure that a single point of failure does not impact the operation of critical and/or essential electrical loads.

The reliability of the FPS and LS and its subsystems shall be consistent with the overall Reliability, Availability, Maintainability and Safety requirements and standards referenced in the *Automatic Train Control* chapter. The FPS and LS availability shall also be consistent with the

availability requirements of the overall project high level thresholds as specified in TBD. FPS and LS availability shall be higher than TBD%.

The FPS and LS Target System shall achieve the following Mean Time Between Failures (MTBF) quantitative requirements:

MTBF for Major Failures: $MTBF_{Mj} \geq$ TBD h

MTBF for Minor Failures: $MTBF_{Mi} \geq$ TBD h

Human factors contributions to Reliability, Availability, Maintainability and Safety shall be considered as follows:

Mean Time To Travel (MTTT) shall be a fixed value selected by the Authority, based on experience from other high-speed rail operators, reflecting the location of Maintenance of Infrastructure (MOI) facilities and highway access to FPS and LS wayside locations.

The supplier shall demonstrate that a Mean Time to Restore (MTTR) of TBD minutes is achievable. MTTR is a mean value for all FPS and LS units; it includes diagnosis of faults measured from the actual start of work on site, replacing of faulty components, testing, and placing the system back into service in the affected area. MTTR does not include MTTT.

17.5.4 Electrical Room/Yard Layout and Security Considerations

Ideally, HV and/or very heavy electrical equipment (e.g., switchgear, transformers) shall be located at-grade in secured yards that will permit easy installation and future replacement. Otherwise, FPS equipment shall be located in dedicated electrical rooms.

The electrical rooms/yards shall be sized to allow for the equipment, code clearances, equipment placement and/or removal, and future system expansion. The footprint of electrical rooms/yards shall include space for future expansion of at least 25 percent above the required footprint of the initial FPS equipment configuration.

Electrical rooms/yard shall be planned with clear circulation aisles and adequate access to all equipment. Layout shall be neat, and the electrical rooms/yards shall be easy to clean. Horizontal clearances shall comply with requirements set forth by the NEC, CEC, and equipment manufacturer.

FPS equipment, at passenger stations, shall be located inside electrical rooms. Where this is not practicable, the FPS equipment shall be located so it is inaccessible to and out of obvious view of the patrons.

Consideration shall be given to locating heat-producing FPS equipment, outside of enclosed rooms.

Electrical rooms shall have a clear height to the underside of the structure for compliance with requirements of the NEC and CEC and not less than 12 feet. Catwalks shall be provided for all

equipment that cannot be maintained from floor level. Where maintenance or equipment replacement requires the lifting of heavy parts, hoists and hatchways (where applicable) shall be installed and the structure (to which the hoist is attached) shall be designed for the intended loading conditions.

Lighting at the electrical rooms/yards shall be laid out so as not to interfere with equipment. Switched emergency lighting shall be provided in electrical rooms.

The width and height of doorways/gates to electrical rooms/yards shall take into consideration the largest piece of equipment to be placed within the space and shall not necessitate non-standard equipment shipping splits or disassembly on-site of equipment (during placement/removal operations).

All doorways and/or gates at electrical rooms/yards shall be secured. Refer to *TBD* chapter for additional security requirements.

The number and location of electrical rooms shall be determined so that the electrical loads served are located within reasonable distances.

The space above suspended ceilings shall be adequate to run conduits and cable tray systems. Normally allow a 3-foot-minimum clearance from the top of light fixtures to the bottom of structural ceiling or steel girders (where girders are used to support the ceiling) for the installation of conduits and cable tray systems.

17.5.5 Housekeeping Pads

Housekeeping pads shall be provided for all floor-mounted FPS equipment. Housekeeping pads shall be at least 3 inches larger than the mounted equipment on all sides and at least 4 inches high (above finished floor surface).

17.5.6 Operating Instructions

Posted operating instructions (that are required for manually operated electrical equipment) shall be provided in all electrical rooms/yards. The instructions shall consist of simplified instructions and diagrams of equipment, controls and operation of the systems, including selector switches, main-tie-main transfers, automatic transfer switch by-pass, UPS by-pass, etc. Instructions shall be framed and posted adjacent to the major equipment of the FPS.

17.5.7 FPS Designs in Rooms Housing Sensitive Electronic Equipment

Examples of rooms housing sensitive electric equipment include operations/regional central controls, train control rooms, and communications rooms.

Non-linear loads generate harmonic currents that are reflected into the neutral service conductors. Exercise caution when designing circuits and selecting equipment to serve non-linear loads.

Avoid running unshielded metallic signal or data lines parallel to power feeders.

Where metallic signal or data lines must be routed in noise prone environments, use shielded cables or install wiring in ferrous metal conduit or enclosed cable trays.

Metallic signal or data lines and equipment shall be located at a safe distance from arc-producing equipment such as line voltage regulators, transformers, battery chargers, motors, generators, and switching devices.

Isolation transformers, electronic power distribution panel boards or power conditioners shall be provided to serve critical electronics equipment loads within the room (where the equipment is housed).

Refer to *Grounding and Bonding Requirements* chapter, and *Electromagnetic Compatibility and Interference* chapter for additional design requirements to mitigate impacts to sensitive electronic equipment from FPS equipment and/or conductors.

17.5.8 Enclosure Ratings

All indoor (except as defined below) electrical equipment enclosures shall be rated as National Electrical Manufacturers Association (NEMA) 12 or 3R.

All outdoor electrical equipment enclosures located above ground shall be rated as NEMA 4.

All electrical equipment enclosures located underground (e.g., tunnel, cross passages, ventilation structures [e.g., shafts and stairways] and sump pump structures), elevators and escalator pits shall be rated as NEMA 4X (i.e., stainless steel) and comply with the requirements specified in NFPA 130.

Alternative equipment enclosure NEMA classifications to those noted above that are suitable for the environment to which the equipment is exposed may be considered but should be submitted as a Design Variance Request for the Authority’s approval.

17.5.9 Underwriters Laboratories Rating

All FPS and LS infrastructure shall be Underwriters Laboratories (UL) listed for the intended operating environment and application.

17.5.10 Future Equipment

The FPS design shall include provisions for equipment anticipated to be added in the future, including, but not limited to, security and baggage screening equipment, elevators, escalators, fare gates, bus signs, and pay telephones. Provisions shall include electrical distribution capacity, space for future circuit breakers, and rough-in conduit/boxes to future equipment locations. Rough-in conduit shall be planned and installed in the same fashion as circuits provided, so that when future equipment is installed, surface-mounted conduit can be avoided.

17.5.11 Earthquake Engineering Design

Equipment design, including device mounting, supports, materials, and installation methods shall conform to the design requirements outlined in IEEE 693 and specified in the Seismic Chapter.

17.5.12 Environmental and Operational Engineering Design

The facilities housing the FPS equipment and/or housekeeping pads/foundations (on which FPS equipment is mounted) shall be protected from the known 500-year flood levels.

Refer to the *Drainage* chapter for additional requirements.

Where the FPS equipment placement is exposed to winds, the associated structural bracing designs shall consider wind loading and compute it by using a basic wind speed of 80 miles per hour, Exposure D and a Wind Importance Factor (I) equal to 1.15.

Refer to the Structures chapter for additional requirements pertaining to slipstream affects.

17.5.13 Calculations

17.5.13.1 Voltage Drop

The following voltage drop criteria shall apply to the FPS. Compliance to the requirements shall be demonstrated using the calculations specified in the contract documents:

A. Sensitive Electronic Equipment

- 1.5 percent or less on branch circuit conductors
- 2.5 percent or less on combined feeder and branch circuit conductors

B. Power and Lighting Circuits

- 3 percent or less on feeder circuit conductors at the farthest field device in the circuit
- 5 percent or less on combined feeder and branch circuit conductors at the farthest field device in the circuit

C. Tunnel Ventilation Fan Motors

- 10 percent or less on feeder circuit conductors to fan motor during initial start-up conditions
- 3 percent or less on feeder circuit conductors to fan motor during steady state conditions

D. LV Motors

- 10 percent or less on feeder circuit conductors to LV motor during initial start-up conditions
- 3 percent or less on feeder circuit conductors to LV motor during steady state conditions

E. Emergency Standby Generator System

- 5 percent or less on feeder circuit conductors to the 480 V switchboard during initial start-up conditions
- 3 percent or less on feeder circuit conductors to the 480 V switchboard during steady state conditions

17.5.13.2 Demand Factor

The following demand factors shall be used when sizing equipment and/or conductors:

Table 17-1: Demand Factor

Lighting and Signs	1.0 x connected load
Emergency Lighting	1.0 x connected load
ATC Equipment	1.0 x connected load
System-wide Communications Equipment	1.0 x connected load
Facility Communications Equipment	1.0 x connected load
Escalators	0.85 x connected load
Elevators	0.5 x connected load
HVAC Equipment	0.8 x connected load
Tunnel and/or Emergency Ventilation Equipment	1.0 x connected load
Chiller Plant	0.8 x connected load
Fare Collection Equipment	0.5 x connected load
Drainage Pumps and Ejectors	0.5 x connected load
Convenience Receptacles	1.5 ampere each
Electric Utility Service/TES Service to FPS	1.0 x connected load

17.5.13.3 Harmonics

Selected equipment and light fixtures shall introduce none or limited harmonic distortion into the electrical power system. The design shall comply with applicable institutional and/or industry standards (e.g., IEEE 519).

17.6 Supply Voltage

17.6.1 Medium and High Voltage Electrical Loads

Voltage rating of tunnel ventilation axial and/or jet fans above 100 horsepower shall be 4.16 kilovolts (kV) ac, 3 Phase, 60 Hertz (Hz) or greater.

17.6.2 Low Voltage Electrical Loads

AC power for general facilities shall be supplied at nominal 480 V ac, three-phase, 4-wire, 60 Hz. For loads 50 kVA and higher with feeder length of 1,500 feet or longer, an evaluation shall be performed to determine the more cost-effective system voltage between 4,160 V ac and 480 V ac. Alternate voltage levels may be used where practical and safe for the equipment. Other nominal voltages shall be obtained by use of dry-type transformers.

The rated voltages of the equipment shall be as follows:

Table 17-2: Rated Voltages of the Equipment

Item No.	Equipment		Electrical Requirements	
1	Advertising		120 V	single-phase (if any)
2	Area and parking lot lighting		277 V	single-phase
3	Auxiliary service to tie breaker stations		480 V	three-phase
4	Communication equipment and alarm systems		120/208 V	three-phase 4-wire, grounded neutral
5	Convenience receptacles		120 V	single-phase
6	Dry-type Transformers		480 V to 120/208 V	3-wire, delta primary, 4-wire, wye secondary
7	Electric clocks		120/208 V	three-phase 4- wire, grounded neutral
8	Exit signs		120 V	single-phase (if any)
9	Fare collection equipment		120/208 V	three-phase four wire
10	Fluorescent lighting		277 V	single-phase
11	Heaters for motors or electric equipment		120 V	2- or 3-wire single-phase
12	Heaters (> 5,500 Watts)		480 V	three-phase
13	HID lighting		277 V	single-phase
14	Incandescent lighting		120 V	single-phase
15	Motors	0.37 kW to 100kW	480 V	three-phase
		Under 0.37 kW	120 V	single-phase
16	Motor control		120 V	single-phase
17	Power receptacles		480 V 120 V	three-phase single-phase
18	Train control and signal systems		120/208 V	three-phase 4-wire, grounded neutral
19	Tunnel lighting		277 V	single-phase

Maintenance-of-Equipment-Facilities Special Equipment (John\James – is this the generic term for the rolling stock and infrastructure maintenance facilities and is it defined somewhere) – The rated voltages of the equipment shall be as follows:

Table 17-3: Rated Voltages for Yard and Shops Special Equipment

Item No.	Equipment	Electrical Requirements	
1	20 ton hydraulic press	480 V	three-phase
2	89 kN overhead bridge crane	480 V	three-phase
3	Abrasive Blast	480 V	three-phase
4	Air compressor	480 V	three-phase
5	Analog converter	120 V	single-phase
6	ATC tester	120 V	single-phase
7	Audio visual equipment for emergency exit stairs in places of refuge	120 V	single phase
8	Axle cleaner	480 V	three-phase
9	Axle lathe	480 V	three-phase
10	Band saw	480 V	three-phase
11	Battery bench	120 V	single phase
12	Battery charger	480 V	three-phase
13	Belt grinder	480 V	three-phase
14	Belt sander	240 V	single-phase
15	Bench grinder	120 V	single-phase
16	Buffer grinder	480 V	three-phase
17	Card test console	240 V	three-phase
18	Chop saw	480 V	three-phase
19	Cleaning station	480 V	three-phase
20	Cleaning tank	480 V 240 V 120 V	three-phase three-phase single-phase
21	Coolant system	120 V	single-phase
22	DC TIG/MJG welder with trailer cart	480 V	three-phase
23	De-ionizer	120 V	single-phase
24	Double-ended grinder/dust collector	120/240 V 120V	single-phase single-phase
25	Drill bit grinder	480 V	three-phase
26	Drill grinder	480 V	three-phase
27	Drill sharpener	240 V	single-phase
28	Dust collector	480 V	three-phase

29	Electrode oven	480 V	three-phase
30	Electronic repair areas (electrical requirements will change, depending on systems purchased)	120 V	single phase
31	Engine lathe	480 V	three-phase
32	Event recorder	120 V	single-phase
33	Freon collection system	120 V	single-phase
34	Glass bead	120 V	single-phase
35	Grit blast	120 V	single-phase
36	“H” frame press	480 V	three-phase
37	Hazardous materials storage building	208/120 V	single-phase
38	High pressure washer	480 V	three-phase
39	High-pressure hot water generator cleaner	480 V	three-phase
40	Hi-pot tester	480 V	three-phase
41	Hi-volt power supply	480 V	three-phase
42	Honing machine	480 V	three-phase
43	HVAC	240 V	three-phase
44	Hydraulic pinch-nibbler	480 V	three-phase
45	Hydraulic press	120 V	single-phase
46	Jet spray washer	480 V	three-phase
47	Jib crane	480 V	three-phase
48	Jockey pumps	480 V	three-phase
49	Lathe	480 V 120 V	three-phase single-phase
50	Logic control	240 V	single-phase
51	Magna flux machine	480 V	three-phase
52	Maintenance-of-Infrastructure building	480 V 120 V	three-phase single-phase
53	Master controller	120 V	single-phase
54	Material lift	480 V	three-phase
55	Metal shear	240 V	three-phase
56	Milling machine	480 V	three-phase
57	Mini fume extractor	120 V	single-phase
58	Oven	480 V	three-phase
59	Overhead bridge crane	480 V	three-phase
60	Overhead crane	480 V	three-phase
61	Paint booth	480 V	three-phase
62	Parts washer	120 V	single-phase
63	Pedestal grinder	480 V	three-phase
64	Pipe threading machine	208 V	single phase

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65	Portable electrostatic fume processor	480 V	three-phase
66	Power brake	480 V	three-phase
67	Propulsion	120 V	single-phase
68	Radial drill	480 V	three-phase
69	Repair booth	480 V	three-phase
70	Repair stand	120 V	single-phase
71	Roller	480 V	three-phase
72	Sander	240 V	single-phase
73	Saw band	120 V	single-phase
74	Shear	480 V	three-phase
75	Shop drill press	480 V	three-phase
76	Small grinder	120 V	single-phase
77	Small parts paint booth	480 V	three-phase
78	Solvent rinse station	120 V	single-phase
79	Spot welder	208 V	single-phase
80	Surface grinder	480 V	three-phase
81	Table saw	480 V	three-phase
82	Test bench	120 V	single-phase
83	Test rack	120 V	single-phase
84	Test stand	240 V	single-phase
85	Tester	120 V	single-phase
86	Tire press	480 V	three-phase
87	Toilet control	120 V	single-phase
88	Toll and cutter grinder	480 V	three-phase
89	Tool grinder	480 V	three-phase
90	Train wash building	480 V	three-phase
91	Train wash building	120 V	single-phase
92	Trash compactor	Dependent on equipment purchased	
93	Truck hoists	480 V	three-phase
94	Truck repair hoist	480 V	three-phase
95	Truck unloading lift or dock leveler	480 V	three-phase
96	Turntables	Manually operated	
97	Ultrasonic cleaner	480 V	three-phase
98	Vehicle hoist system	480 V	three-phase
99	Vertical band saw	480 V	three-phase
100	Vertical mill	480 V	three-phase
101	Washer	240 V	three-phase
102	Welder	208 V	single-phase
103	Welding bench	480 V	three-phase

104	Wheel truing machine	480 V	three-phase
105	Wheel/axle press	480 V	three-phase
106	Wheel/hub boring machine	480 V	three-phase
107	Winding Machine	120 V	single-phase
108	Workbench	120 V	single-phase

17.7 New Electrical Utility Services

17.7.1 General Requirements for New Electrical Utility Services

The design and construction of new electrical utility services shall comply with the requirements of the local electrical utility service provider. Refer to the *Utility* chapter for additional requirements

The service entrance location for the FPS shall be determined concurrently with the development of design. Space-planning documents and standards for equipment furnished by the local electrical utility service provider shall be incorporated into the design. Locations for transformers, vaults, meters, and other electrical utility service items must be coordinated with the architectural design of the facility to avoid detracting from the facility's appearance.

The local electrical utility service provider shall own and maintain all local electrical utility service provided equipment and cables.

The location of the service entrance within the Authority's facilities and/or trackside equipment enclosures shall be assumed to be available to the local electrical utility service provider's personnel 24 hours a day/365 days a year. Accordingly, the location of the service entrance needs to consider the security guidelines that relate to limited access to secured areas/facilities by third parties. Refer to *TBD* chapter for additional security requirements with regards to limited access to secured areas.

Where the normal and backup power services to a facility are supplied by the local electrical utility service provider, the following requirements shall apply:

- The services shall be independent (i.e., originate from separate utility transformer/switchgear banks, routed on separate overhead or underground infrastructure for the majority of the route (between distribution network and the Authority's right-of-way).
- One of the power services shall be rated (e.g., Block 50) such that it is still energized and available to the Authority during roaming blackouts and/or load shedding by the electrical utility service provider.

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Where adjacent facilities necessitate separate electrical utility services from the local electrical utility service provider, the electrical utility services shall be independent (i.e., originate from separate utility transformer/switchgear banks, routed on separate overhead or underground infrastructure for the majority of the route (between distribution network and the Authority's right-of-way).

Electrical utility services for the Authority's facilities and/or trackside equipment enclosures shall be connected to the local electric utility service provider's nearest and available electrical line(s), which have adequate capacity for the anticipated electrical loads and meet the previously noted requirements.

The design of the FPS protection scheme shall prevent the "paralleling"/interconnection of the electrical utility services to other power sources at the Authority's facilities and/or trackside enclosures.

Refer to the *Utilities* chapter for additional requirements.

17.7.1.1 Tunnel Ventilation System

In the case of facilities and/or structures that house tunnel ventilation fan motors, the electrical utility services shall have sufficient reserve capacity to facilitate the designed operational modes of the fan motors during normal and emergency modes of operation. Refer to the *Mechanical* chapter for additional mechanical and operational mode requirements.

17.7.2 Metering Requirements

The design, manufacture and installation of the utility metering section shall be in accordance with the standard specifications of the Electric Utility Service Equipment Requirements Committee and the local electrical utility service provider.

17.7.2.1 Facilities and Trackside Equipment Enclosures

Three-phase metering-power quality meters shall be provided with the following metering features: A, V, W, Wh, Wcost, Var, Varh, VA, Vah, Hz, and PF in true RMS and/or displacement (fundamental) qualities.

17.7.3 Concessionaires

Concession areas shall be provided with meter base, main circuit breakers, and panel boards for measurement of power consumption of future private concessions.

Electrical service for concession areas shall be independent of the electrical services to the facilities and shall be connected to the local electric utility service provider's nearest and available electrical line(s).

17.8 Emergency Power Supply Systems

Emergency power-supply system design shall conform to the NEC, CEC, NFPA 101, NFPA 110, NFPA 111, NFPA 130, and IEEE 446. Additionally the design and as-built installation of the emergency power supply system shall comply with all applicable codes, standards and ordinances as required by the local fire department.

Emergency power supply system electrical infrastructure shall include all equipment, wires, cables, conduit, and tray connected to an emergency standby generator, UPS and/or dc battery system, and associated with the tunnel ventilation system. This infrastructure shall be UL listed and certified as suitable for use in an emergency system.

The following minimum fuel/battery storage capacities shall be applied to the CHSTP:

Table 17-4: Minimum Fuel/Battery Storage Capacities

Emergency Standby Generator (fuel)	30 hours
Uninterruptable Power Supply [ATC/Comms/etc.] (battery)	4 hours
Uninterruptable Power Supply [Lighting] (battery)	90 minutes
DC Battery System (battery)	4 hours

Conductors associated with the emergency power supply system (including, but not limited to, from the power source to the switchboard/unit substation/panelboard and “downstream” to the field devices, including interconnections between field devices) shall be run in separate conduit, tray, boxes and so forth, independent of conductors associated with other electrical loads (e.g., non-essential).

Fuel tank and battery placement shall comply with the requirements specified in applicable building codes.

Battery chargers (associated with UPS and/or dc battery systems) shall be interlocked with the mechanical ventilation system for the respective battery room to prevent battery charging without ventilation.

17.8.1 Emergency Power Supply Equipment

17.8.1.1 Emergency Standby Generators

Emergency standby generators shall be diesel-engine driven; output 480/277 Volts, 60 Hz, 3 phase and 4 wire; and be designed to start-up by manual initiation and automatically.

Emergency standby generators and associated fuel tanks shall be located at street level with roadway access.

17.8.1.2 Uninterruptible Power Supplies

Separate UPS equipment shall be provided for each of the following electrical loads:

- Emergency Lighting
- Core Systems (i.e., TES, ATC and SCS)
- Facility Communication Systems and other facility essential electrical loads
- Management Information Systems

17.8.1.3 DC Battery Systems

Separate dc battery system equipment shall be provided for each of the following electrical loads:

- Core Systems (i.e., TES, ATC and SCS)
- Facility Communication Systems and other facility essential electrical loads

17.9 Sustainable Power Sources

17.9.1 Photovoltaic and Wind Systems

The use of sustainable power sources is encouraged whenever feasible. This is especially advantageous for 'off-grid' trackside facility/equipment applications where bringing in a utility electrical service would be costly or the load does not justify it. Even when utility service would be economically feasible, photovoltaic or wind options should be considered.

These systems, if used, shall meet the following requirements:

- Photovoltaic panels or wind turbines shall be provided with substantial and efficient mounting assemblies and located to maximize energy capture. Complicated solar-tracking mechanisms for photovoltaic arrays shall be avoided unless they can be demonstrated to offer substantial operational or efficiency advantages that overcome higher maintenance costs.
- Photovoltaic panels and wind turbines shall be sunlight and weather-resistant and suitable for remote, unattended locations.
- Distribution system and loads shall be designed to operate on 12, 24, or 48 VDC power supply unless it is infeasible for the load to be served. This will avoid the added complexity and maintenance of an inverter power supply.
- System shall include a charge controller to manage battery charging and include appropriate circuit isolating disconnects for maintenance of various components.
- Batteries shall consist of maintenance-free, valve-regulated, pocket-plate nickel-cadmium cells sized to maintain power to equipment for the expected period of time that solar or wind power will not be available.

- System enclosures shall be designed to protect components from vandalism and weather and also protect from temperature extremes. Enclosures shall be ultraviolet ray-stabilized, fiberglass reinforced epoxy or stainless steel to resist corrosion.

17.10 Facility Power System Equipment

17.10.1 High Voltage Switchgear

The HV switchgear assembly and all components shall be designed in accordance with the latest applicable standards of ANSI, NEMA and the IEEE; and comply with the engineering and operating standards requirements of the local electrical utility service provider (e.g., Section 400 of the Electric Utility Service Equipment Requirements Committee book). The HV switchgear assembly shall have sufficient short circuit and impulse withstand capability to operate safely.

Each switchgear assembly shall include a metering compartment consisting of voltmeter, ammeter, kilowatt meter, kilowatt-hour meter with peak demand indicator and pulse output, and kilovolt-ampere reactive hour meter with required switches, fuses and sensors.

Circuit breakers in switchgear shall operate with 125-VDC control power. The intent of the design shall be to keep the number of separate battery banks to a minimum and to remain in compliance with local electrical utility service provider requirements.

17.10.2 High Voltage Transformers

HV transformers shall be dry-type when used indoors and dry or liquid filled type when used outdoors. Construction shall be in accordance with applicable sections of ANSI and NEMA standards.

17.10.3 High Voltage Motor Control Centers

TBD

17.10.4 Unit Substation

Each electrical utility service entry distribution system shall contain a primary-fused disconnect switch and a medium voltage to 480/277 V dry-type cast resin transformer. The 480 V switchgear shall consist of main breakers, tie breakers, and switchboards with distribution feeder breakers. The tie breaker shall close automatically after either one of the main breakers opens on undervoltage. The tie breaker shall open after restoration of normal voltage to the main breaker. The transformers shall be equipped with forced-air cooling under thermostat control and shall be provided with a two-stage over-temperature device with alarm contacts.

The unit substation shall be designed to carry the forced-air-cooled rating of a single transformer, or the sum of the full load losses of both transformers multiplied by 0.80. Each unit substation 480 V switchgear will have approximately 20 percent spare spaces bussed and ready

to accept future breakers, unless such provision requires an additional section, in which case space shall be provided for the additional section.

17.10.5 480/277 V ac Switchboards/Switchgear

Switchboards/switchgear shall consist of circuit breakers positioned in a metal-enclosed, free-standing enclosure together with all associated meters, relays, instrument transformers, heaters, and all other accessories as required to provide complete and operable switchboards/switchgear.

Where applicable, switchgear shall be arranged for attachment to a transformer enclosure as a component of a unit substation

17.10.6 Panelboards (480/277 V ac, 208/120 V ac, 250/125 V dc)

Panelboards shall be circuit breaker type. The interrupting rating of the circuit breakers shall be selected so as to safely interrupt the calculated fault currents.

Panelboards located within finished spaces shall be flush mounted; panelboards located within unfinished spaces may be either flush or surface mounted.

Lighting panelboards shall contain addressable circuit breakers that are compatible with and controlled by a lighting programmable controller.

Panelboards shall be placed near or central to their loads. They shall be located in the electrical rooms or suitable ancillary rooms provided they are easily accessible to maintenance personnel.

17.10.7 Low Voltage Transformers

Transformers shall be two winding, LV, dry type suitable for indoor application and step down of the primary voltage (480 V ac) to a 208 Y/120 V ac secondary level.

17.10.8 Low Voltage Circuit Breakers/Switches

17.10.8.1 480 V ac Circuit Breakers/Fused Disconnect Switches

Heavy duty circuit breakers or fused disconnect switches shall be provided where required by the NEC and/or CEC as a means to disconnect equipment from its feeder, when the equipment is not within the sight of either the feeder breaker or motor controller, or where it is advantageous to separate feeder from electric loads to be supplied by others.

A circuit breaker and/or fused disconnect switch shall be provided in the same room as a manual/automatic transfer device for each power source on the line side of the equipment.

17.10.8.2 480 V ac Manual Transfer Device

A manual transfer device shall be used where there is more than one power source feeding the same electric load, and one of the power sources originates from a portable generator set. It

shall be designed such that only one power source can supply power without the possibility of paralleling the two sources.

17.10.8.3 480 V ac Automatic Transfer Device

An automatic transfer device (i.e., circuit breaker) shall be used where there is more than one power source feeding the same electric load. It shall be designed such that only one power source can supply power without the possibility of paralleling the two sources. These shall be electrically operated. All automatic transfer devices shall have a manual bypass feature.

17.10.9 Motors, Starters and Controls

In general, motor control centers with motor-circuit-protector combination starters shall be used for 480-volt motors. Control centers shall be equipped with either a main circuit breaker or a fused circuit breaker with main busses adequately braced to withstand the available short-circuit current. Individually mounted motor circuit protector combination starters may be used where they can be located in a physically secure area.

17.10.10 Receptacles

In public areas, receptacles shall be spaced not more than 100 feet apart and shall be located flush in a wall or column. The circuit shall be energized only for operation by authorized personnel. In public areas, no more than six outlets shall be connected to a branch circuit.

In non-public areas and non-office environments, receptacles may be surface mounted and shall be spaced not more than 20 feet apart and shall be supplemented where needed for fixed equipment. Receptacles in non-public areas in facilities shall be of the duplex 20-amp minimum rating, grounded type. In ancillary or service areas, no more than 5 duplex outlets shall be connected to a branch circuit.

Receptacles in public and trackside locations shall be ground-fault circuit interrupters (GFCIs) and weatherproof. A Ground-Fault Circuit Interrupters (GFCI) receptacle shall be used where ground fault protection is required and use of a GFCI circuit breaker for the receptacle circuit has not been provided.

Adjacent receptacles shall not be placed on the same feeder/branch circuit.

All other receptacles shall be rated for the intended working environment and comply with the requirements of the NEC and CEC.

The requirements for receptacles at TES, ATC, and SCS facilities shall be specified elsewhere in the design criteria and/or contract documents.

17.11 Specialized Electrical Equipment and/or Loads

17.11.1 Maintenance-of-Equipment Facilities

17.11.1.1 Facility Power Infrastructure

The design of the FPS at the Maintenance-of-Equipment Facilities shall include electrical infrastructure (located below car floor level) that permits the power up of the stationary trainset onboard auxiliary systems when the Overhead Contact System (OCS) is de-energized. The electrical infrastructure shall be provided on all tracks within the noted facilities and and\or at storage tracks. The following features shall be included in their design:

- Utilization voltage shall be 480 V ac, 3 phase, 60 Hz.
- At least 4 connection points (spaced at intervals so as to permit connection to the Rolling Stock) shall be provided along each track.
- A local disconnection device shall be provided with each connection point to provide local isolation. The design of the disconnection device shall include visual indication of energization/de-energization and an interlock.
- Adjacent connection points and associated disconnection devices shall not be placed on the same feeder/branch circuit.
- Each extension cable, associated with each connection point, shall be sufficiently long enough to connect to Rolling Stock on the adjacent track(s).

Refer to the *Rolling Stock-Core Systems Interfaces* chapter for Rolling Stock interface requirements.

17.11.2 Elevators

This equipment is considered essential during an emergency condition, and shall be fed from the nearest generator bus. The electrical power supply to the equipment shall consist of a nominal 480 V, three-phase, 60 Hz supply terminated in a fused disconnect switch in the elevator machine room.

A 208Y/120-volt, 3-phase, 20-amp, originating from the generator bus, shall be provided for hoistway lighting and receptacles in accordance with the applicable code requirements.

A 120-volt, 20-amp service shall be provided for cathodic protection circuit in the elevator machine room.

GFCI duplex weatherproof, 20 ampere, 120 V receptacles shall be provided in elevator pits.

17.11.3 Escalators

The power supply for each escalator shall consist of a 480-volt, 3-phase supply terminated in a circuit breaker in the escalator machine space. For an escalator with a rise of 20 feet or less, the

power supply shall be sized at 1 hp per foot of rise. For an escalator with a rise greater than 20 feet, the power supply shall be sized at (20 + 1.5 (H-20)) hp, where H is the total escalator rise in feet.

A 208Y/120-volt, 3-phase, 20-amp service is required for each escalator for maintenance lights, light switch, and receptacle in the machine space. This service is not to be used for emergency power.

Escalator control connections to exit signs and roll-down gates shall be provided. Refer to *TBD* chapter for the local control and indication requirements.

GFCI duplex weatherproof, 20 ampere, 120 V receptacles shall be provided in escalator upper and lower pits.

17.11.4 Sump Pumps

Each pump station shall be equipped with 2 or more pumps. These shall be fed from different buses (i.e., normal and backup) nearest to the pump station. Only 1 pump at a time may be out of service except during an area-wide power outage.

17.11.5 Tunnel Ventilation System

Facilities (e.g., portal facilities, mid-tunnel ventilation structures) that contain a tunnel ventilation system shall have the following key features incorporated into the FPS design for these facilities (in addition to complying with the requirements of NFPA 130):

- An HV transformer per power source to transform the incoming power source to the utilization voltage (e.g., 4160 V ac).
- Main and tie circuit breaker arrangement to permit the tunnel fan motors to be powered by either incoming power source.
- Two feeder circuit breakers to the downstream transformation and distribution equipment to permit maintenance/testing of a feeder circuit breaker, while still keeping the downstream electrical loads energized.
- Tunnel fan motors, that are used to ventilate the same tunnel, shall be directly fed from different 4.16 kV buses.

17.11.6 Ticket Vending Machines and Fare Gates

Each passenger station is equipped with ticket vending machines, fare gates and an associated ticket vending machine (TVM) control system. Two under-floor ducts for power and signal circuits shall be installed underneath the fare gate and ticket vending machines. Adequate junction boxes shall be provided wherever the raceways change direction. All other raceways for signal and power circuits shall be metallic conduits.

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The power supply to TVM equipment shall be fed from the panelboard located in the nearest electrical room. Adjacent TVM equipment shall not be placed on the same feeder/branch circuit.

Refer to the *Stations* chapter for additional requirements pertaining to TVM equipment and fare gates.

17.11.7 Panels

17.11.7.1 Local Control Panel

A Local Control Panel (LCP) shall be provided at all electrical rooms where HV switchgear, HV transformers, HV motor control centers, unit substations, 480 V ac switchboards and so forth are located.

The design of the LCP shall include the following features:

- A mimic bus depicting the electrical interconnection of the equipment.
- Visual indication on the position of circuit breakers and switches.
- Control switches to operate circuit breakers and switches.
- A touch screen annunciation panel, with pull-down menus, that permits operations and maintenance personnel to ascertain the status of all equipment (noted in Section 17.17, Electrical Discrete and Serial I/O Point Requirements) and undertake diagnostic checks.

The LCP design shall include a local and remote control switch, which, during normal operation, shall be set to remote—thereby permitting the Operations/Regional Control Center (O/RCC) to monitor and control the local FPS equipment. Once the control switch is moved to the local position, the O/RCC display shall note the local control status, and the O/RCC shall not be permitted to operate the associated FPS equipment.

17.11.7.2 Emergency Walkway Lighting Control Panels

An Emergency Walkway Lighting Control Panel (EWLCP) shall be provided at an electrical room that provides feeder/branch circuits to emergency walkway light fixtures.

The design of the EWLCP shall include the following features:

- A mimic bus depicting the electrical interconnection of the equipment and trackside distribution to light fixtures (include depiction of extent of lighting circuit and which track it applies to).
- Control switches to operate circuit breakers and switches.

The requirements for control panels associated with access control, fire detection, tunnel ventilation and so forth are specified elsewhere in the design criteria and/or contract documents.

17.11.8 Interface Termination Cabinet

The interface wiring between the FPS and the SCADA and/or BAS systems (see Section 17.17, Electrical Discrete and Serial I/O Point Requirements) shall reside in an Interface Termination Cabinet (which will act as a demarcation between the communication and electrical disciplines/trades) located at each electrical room, within 10 feet-0 inches of an entrance doorway.

All functions that are monitored and/or controlled shall be uniquely identified at the Interface Termination Cabinet.

17.11.9 Vehicle Battery Charging Facilities

Vehicle battery charging facilities shall be provided at passenger stations, and Rolling Stock and infrastructure maintenance facilities

These facilities shall meet the following requirements:

- The power source to the vehicle battery facilities shall be separately revenue metered from the adjacent facility.
- The distribution cables, between the power source and each vehicle battery charging facility, shall be routed via an underground ductbank and structures. No other FPS or other system cables shall be routed in the ductbank.
- The placement of the vehicle battery charging facilities and routing of associated ductbanks shall be coordinated with site lighting, security/communication field devices, other subgrade facilities, site-work and landscaping.
- Enclosures shall be designed to protect components from vandalism and weather and also protect from temperature extremes. Enclosures shall be ultraviolet ray-stabilized, fiberglass reinforced epoxy or stainless steel to resist corrosion.
- At least TBD % of parking spaces at each passenger station shall be equipment with vehicle battery charging facilities.
- At least TBD % of parking spaces at each Rolling Stock maintenance facility shall be equipment with vehicle battery charging facilities.
- At least TBD % of parking spaces at each infrastructure maintenance facility shall be equipment with vehicle battery charging facilities.
- A vehicle battery charging facility shall be provided to each designated parking space (i.e., it shall not be shared between adjacent parking spaces).

17.11.10 Specialized Equipment for First Responders (within Tunnels)

The FPS shall be adequately sized and include provisions to permit connection of first responders' equipment at each portal, emergency access or egress shaft, cross passages throughout each tunnel and elsewhere. Refer to the *TBD* chapter for additional requirements.

The point of connection for first responders' equipment shall be designed to be electrically and mechanically compatible with the standardized equipment used by the first responders.

The following requirements shall apply:

- Conductors to any two adjacent points of connection shall originate from different panelboards.
- Panelboards that distribute power to points of connection shall be electrically connected to the normal, backup and emergency power supply sources.

17.12 Lighting System Requirements

The following general requirements shall be incorporated in the lighting design for each area:

- The lighting system design shall be designed to be relatively simple and minimize initial capital costs, as well as frequency and expense of maintenance.
- Lighting shall be designed to be functional, yet complementary to those other aesthetic features in the space that provide an atmosphere of relative comfort, pleasantness and cleanliness of surroundings, and a sense of personal safety and security.
- Adequate lighting levels, uniformity ratios, contrast, and other visibility attributes necessary to stimulate productivity, facilitate the use of facilities by patrons or the useful completion of tasks in a timely yet safe manner, and maintain the appropriate surveillance levels under all ambient lighting conditions shall be provided.
- Lighting designs shall be energy efficient and comply with California Code of Regulations Title 24, CBC Title 24, and all IESNA Recommended Practices, ASHRAE, and ANSI standards.
- Lighting shall be designed to satisfy security requirements and to provide a pleasant and bright environment. Refer to the *TBD* chapter for additional requirements
- Lighting fixture locations shall permit easy accessibility for re-lamping and periodic cleaning.
- Any required illumination shall be arranged and wired so that the failure of any single lighting unit or circuit shall not leave the area in total darkness.
- Lighting shall be designed to avoid "spill" light, objectionable glare, and light trespass.
- Lighting fixtures shall be vandal-resistant in spaces accessible to patrons or to the general public.

- Lighting designs shall effectively control glare or other extraneous reflections in the visual field.
- Lighting shall meet or exceed recommendations in this guide in accordance with all applicable IESNA Standard Practices.
- Manufacturers of lighting fixtures, poles, and accessories there of shall have a minimum of 10 years of reputable performance in the industry.

17.12.1 Quality of Illumination

Lighting designs shall be free from distracting and uncomfortable glare; care shall be exercised to prevent specular reflection on signage, direct glare from exposed lamps, high brightness areas of individual fixtures and reflections in glazing or other specular surfaces.

Uniformity ratios shall not exceed the recommended levels as directed by IESNA.

The color temperature of light fixtures shall be within the ranges specified in the contract specifications. Lamps of the same type within each area of illumination shall have the same color temperature. In areas where different types of light fixtures are required, the color temperature of each type shall be matched as close as practicable to ensure uniformity of color.

Special care shall be taken to avoid objectionable glare to streets, tracks, and adjacent properties. Light fixtures shall be positioned to minimize spill light. Light fixtures shall be provided with internal shielding and located to prevent spill light and glare in the direction of adjacent properties. Light fixtures within 50 feet-0 inches of elevated freeways and overpasses shall be designed to provide absolute cutoff in the direction of moving traffic.

17.12.2 Facility Illumination Levels

The average maintained illumination levels for various areas shall be provided as shown in Appendix 17.A (at the end of the chapter). The normal method for calculating these levels shall be in accordance with the IESNA Lighting Handbook with modifications or other requirements stated herein. The “point to point” method of computing illumination shall be used to verify and substantiate illumination and uniformity lighting levels.

17.12.3 Emergency Lighting and Exit Signs

Emergency lighting design shall conform to the NEC, CEC, NFPA 101, NFPA 130, and IESNA Lighting Handbook.

Emergency lighting shall be designed to maintain a minimum of 10 lux (1 fc) horizontal illumination at the finished floor elevation throughout the areas of pedestrian egress.

Exit lighting fixtures/signs shall be provided to illuminate the designated egress passageways, stairways, and the entrances/exits to stairways. Exit lighting fixtures shall be wall or bracket mounted at a mounting height visible to all occupants within the occupied spaces. Exit lighting

fixtures/signs shall be separately wired from other electrical loads (to the emergency panelboard) and shall be connected to the UPS system.

Emergency lighting for stairways and escalators shall be designed to emphasize illumination on the top and bottom steps or landings. All escalator steps newel and comb lighting shall be on emergency feeder circuits in accordance with NFPA 130. A minimum of 10 lux (1 fc).shall be provided.

All lighting fixtures in the Operation/Regional Control Center, auxiliary spaces housing equipment to operate facilities and/or revenue services, and stairways shall be connected to the UPS system.

Emergency lighting fixtures and exit lights/signs in underground occupancies shall be located so as to minimize the possibility of being obscured by stratified smoke in a fire.

17.12.4 Circulation Roadway Lighting and Roadway Sign Lighting (within the Authority's Right-of-Way)

A uniform nighttime illumination shall be provided on the circulation roadways to enable motorists to quickly, distinctly, and comfortably view the roadway alignment, vehicles, obstacles, or obstructions at extended distances ahead, even during inclement weather. The lighting design shall comply with the latest applicable codes and IESNA Recommended Practices.

Lights shall be located above the sign face such that they are aimed down to minimize sky glow. The minimum lighting level for roadway signs shall be 280 lux (28 fc). The average to minimum uniformity ratio of the levels of illumination on the sign face shall be 6:1. The maximum illumination gradient produced on the sign face shall be 1.2:1.

17.12.5 Street and/or Motorway Lighting

Street and/or motorway lighting shall conform to the standards and/or design requirements of the local and/or State jurisdiction. Refer to the *Civil* chapter for additional requirements.

17.12.6 Parking Structure and/or Lot Lighting

17.12.6.1 Parking Structures (Not Applicable)

17.12.6.2 Parking Lot Lighting

Lighting at surface parking lots shall meet the recommendations in the latest edition of the IESNA RP-20, *Lighting for Parking Facilities*.

Lighting poles shall be located inside of curbs, on traffic islands and walks, and along parking lot perimeter. Placement shall present a minimum obstruction to movement and parking of cars. Where poles are placed near automobile traffic or parking, they shall be protected from

physical damage by a concrete base of at least 2 feet-0 inch–diameter, which extends not less than 2 feet-6 inches above grade.

Light pole positioning shall be as required to meet lighting uniformity ratios, be coordinated with the proposed landscaping scheme and prevent off-property spill light.

17.12.7 Elevator/Escalator Pit Lighting

A compact fluorescent lighting fixture in an IP 65-rated enclosure with a wire guard shall be provided at each elevator and escalator pit location, meeting all recommended illumination levels in Table 17.A (at the end of the chapter) .

17.12.8 Lighting Control System

Artificial lighting shall be controlled automatically where practical by selecting from among various lighting control devices. The most useful controls for increasing lighting energy efficiency are timers, dimmers, photocells, and occupancy sensors.

Control strategies shall be selected based upon the following types of lighting situations:

- Lighting shall be designed to continuously illuminate an area during a combination of hours of darkness and hours of operation. Examples of continuous lighting could be station stops, platforms, vehicle approaches, and parking lots. Suitable controls for continuous lighting are timers and photocells.
- Standby Lighting is similar in design to continuous lighting, except not continuously operated. Standby lighting is turned on automatically when activity is detected in the area or manually as necessary to occupy a space. Standby lighting is suitable only for "instant on" lamps. Examples of standby lighting could be utility closets, offices, or restrooms. Suitable controls for standby lighting include discrete "on/off" switches, occupancy sensors, and dimmers.

Refer to the *Stations* chapter for additional requirements.

17.13 Specialized Lighting

17.13.1 Exterior Lighting at Heavy Maintenance Facility, Terminal Layup/Storage, Maintenance Facilities, and Maintenance-of-Infrastructure Facilities

Lighting shall provide sufficient illumination to permit operations and maintenance activities to be performed safely on a 24-hour, 365-day-a-year basis.

Light fixtures, towers, poles or stanchions shall be designed and located to maximize maintenance accessibility, minimize shadows, glare to adjacent properties/neighborhoods, and avoid interference with operations and other trackside infrastructure.

High mast poles used for area illumination shall be climbable and limited to 100 feet-0 inches. High mast poles shall incorporate light fixture-lowering mechanisms.

The location of light fixtures, towers, poles or stanchions shall not interfere with operations, OCS and/or other trackside Core Systems infrastructure or Rolling Stock movements.

17.13.2 Tunnel /Trench Lighting

Lighting shall be provided in all tunnels and conform to NFPA 101 and NFPA 130. Lighting shall be provided in trenches, where the top of the trench wall exceeds 8 feet-0 inches above rail level.

The lighting at walkway surfaces (including emergency exits, cross passages, thresholds, stairways, walkway ramps, crosswalks and all other means of egress or walking surfaces) shall not be less than 15 lux (1.5 fc) illumination.

The lighting at the trackway floor level shall not be less than 10 lux (1 fc) illumination in the Interior Zone, 20 lux (2 fc) in the Transition Zone and 400 lux (40 fc) in the Threshold Zone. During the nighttime hours, the illumination level should be 5 lux (0.5 fc) and 10 lux (1 fc) in the Threshold Zone only.

The spacing of light fixtures inside tunnels and/or along trenches shall not be within the annoyance range of stroboscopic flicker effect as defined in IESNA RP-22 Tunnel Lighting.

Walkway lighting fixtures shall be powered from two alternating electrical power sources (e.g., every other fixture powered from the same feeder circuit).

17.13.3 Exterior Stairway Lighting

. The types of luminaires to be used are dependent on the location. Either pole mounted or wall mounted luminaires shall be used whichever is more appropriate. See the table in Appendix 17.A (at the end of the Chapter) for recommend illumination levels for stairways.

17.13.4 Access Roadway Lighting (to Trackside Core System Facilities)

Not Used.

17.13.5 Blue Light Stations

Blue light stations shall be provided at the locations as specified in the *TBD* chapter and be designed so as to conform to the requirements of NFPA 130.

Blue light stations and associated duplex outlets shall be supplied from alternate power sources, so that loss of power to a blue light station shall not result in power loss to adjacent blue light stations.

A 120 V ac duplex outlet shall be provided at each blue light station. No more than two outlets shall be fed from the same feeder circuit.

17.13.6 Yellow Lights

Yellow light fixtures shall be installed above all tunnel emergency exit and cross passage doorways. Yellow lights shall have two lamps, each supplied from separate feeder circuits.

17.13.7 White Lights

White light fixtures shall be installed above all fire isolation valves. White light fixture shall be lit when the fire isolation valve is open.

17.13.8 Line Storage, Tail Track, and Turnaround Lighting

Pathway for train operator access shall be illuminated to 25 lux (2.5fc) average at grade with an average to minimum ratio not to exceed 3:1 for operations to be performed safely throughout a 24-hour, 365-day-a-year period.

Lighting designs shall adopt mounting details as required to suit site-specific conditions. The location of light fixtures shall be selected to be easily accessible, to minimize shadows, and to not interfere with any OCS operations, and other trackside systems infrastructure and Rolling Stock movements.

The lighting shall permit the detection of trespassers, observation of switch points by a train operator, and observation of smoke emanating from a Rolling Stock fire.

The lighting design shall not have excessive spill light into surrounding areas.

17.13.9 Vehicle Inspection Pit Lighting

Pits shall be provided with sufficient lighting to illuminate the floor and the underside of Rolling Stock (positioned over the pit) with a minimum of 50 lux (5 fc) in accordance with the IESNA Lighting Handbook.

17.13.10 Security Lighting

Lighting shall be provided such that all areas throughout the facility are illuminated to ensure against unwanted visitors. Fixture shall be vandal resistant. Refer to Appendix 17.A for illumination levels.

17.13.11 Obstruction Lighting

Any structure that the Federal Aviation Administration (FAA) determines will impair the safety of air navigation in and around airports adjacent to the alignment shall be marked and lighted in accordance with the applicable FAA regulations.

17.13.12 Light Pollution Mitigation

The designer must design the exterior lighting using the latest IESNA-TM-11 documentation as a guideline to control the light trespass. All luminaires used shall have a U0 BUG rating (Full Cutoff) in accordance with the IESNA.

17.13.13 Lighting Fixtures

The luminaires for the project shall be constructed of the highest quality materials and designed to provide a minimum of 20 years of operation. All exterior luminaires, along with those interior luminaires that require an occasional wash down, shall be UL listed for Wet Locations and for Direct Spray. The chosen luminaires shall incorporate the most effective source for the application and shall be easily maintainable and removable without the use of tools. No interior luminaries shall be constructed using a fiberglass or polymer housing. All luminaires shall be cast or extruded aluminum with stainless steel hardware.

17.13.14 Poles, Foundations, Bracket Arms and Miscellaneous Hardware

All poles shall be galvanized round-tapered steel constructed to provide the ultimate security during inclement weather. All the poles shall include a grounding lug positioned in the pole opposite the reinforced hand hole. Additionally, all poles shall incorporate an internal vibration dampener to minimize vibration during steady winds or structural vibrations. The bracket arms shall be constructed using 2-inch schedule 40 tubing bent to the desired shape and completely galvanized after fabrication. Any holes that are required for mounting of accessories on the pole must be made during the manufacturing process and before any galvanizing or surface finishing is performed. All pole hardware shall be stainless steel.

17.14 Raceway Systems

17.14.1 Conduit Types

17.14.1.1 Galvanized Rigid Steel/Polyvinyl Chloride-Coated GRS

Only galvanized rigid steel (GRS) conduits and accessories shall be provided for power, control, and communications, except in underground or concrete encased ductbanks.

Only GRS conduit and accessories shall be provided for all installations in tunnels, stations under platform chase, sump pump structures, and ventilation structures including tunnel ventilation fans, lighting and sump pumps, except when conduits are embedded in concrete.

Polyvinyl chloride (PVC)-coated GRS conduit sections shall be provided for transition between embedded conduit and the above-ground metallic conduit. PVC within concrete floors/walls/slabs shall be terminated with a male adapter and PVC-coated GRS.

17.14.1.2 Electrical Metallic Tubing

Electrical metallic tubing (EMT) may be run exposed 10 feet-0 inches above finished floor (A.F.F.) or concealed in walls and ceilings, where approved by the Authority. EMT may be used below 10 feet–0 inches A.F.F. for circuits in exiting walls or ceilings but shall not have an exposed length exceeding 3 feet-0 inches.

EMT shall not be installed in equipment rooms (i.e., rooms containing traction power, communication, train control, electrical and mechanical equipment), tunnels, subways, utility chases, under platform utility chases, under platforms, fire command post rooms, concourse level ceilings, outdoor locations, and where exposed to weather.

All emergency power supply source power circuits, lighting circuits, security circuits, communication circuits, fire alarms, service entrance, emergency system (vent fans, dampers, pumps, generators), and critical loads for train control circuits shall not be installed in EMT.

17.14.1.3 Liquid-tight Flexible Metal Conduit

Liquid-tight flexible metal conduit shall be provided only where required for flexibility such as connections to vibrating equipment and across joints subject to differential movement, and where required so that liquids tend to run off the surface and not drain toward fittings.

Liquid-tight flexible conduit shall be used in wet or damp locations.

17.14.1.4 Fiberglass Reinforced Epoxy /PVC

Fiberglass reinforced epoxy and/or PVC schedule 40 electrical conduit shall be provided only when embedded in concrete building or structure, parking structures, slabs and walls, pole foundations, or where required in short sections for electrical isolation.

17.14.2 Conduit Fill Ratio

Conduit fill ratio shall comply with the requirements as specified in the NEC and CEC.

17.14.3 Conduit Sizes

The following minimum conduit size restrictions shall apply to the CHSTP:

- Galvanized Rigid Steel Conduit – 3/4-inch diameter or larger for exposed locations and 1-inch diameter or larger for embedded locations.
- PVC Coated Galvanized Rigid Steel Conduit – 3/4-inch diameter or larger for exposed locations and 1-inch diameter or larger for embedded locations.
- Electrical Metallic Tubing – 3/4-inch diameter or larger for exposed locations and 1-inch diameter or larger for embedded locations.
- Liquid-tight Flexible Metal Conduit – 3/4-inch minimum diameter.

- Fiberglass Reinforced Epoxy or PVC Schedule 40 Conduit – 3/4-inch diameter or larger for exposed locations and 1-inch diameter or larger for embedded locations. For concrete slabs less than 5 inches thick or elevated prestressed concrete decks, 3/4-inch conduits may be used.
- Innerduct – 1-inch minimum diameter.

Conduit runs within finished areas (e.g., offices, concourses) shall be concealed in floor slabs, walls, ceiling slab or hung ceilings. Wiring devices shall be flush mounted.

17.14.4 Tray

Tray systems shall be engineered to comply with the following requirements:

- The tray system shall be fully enclosed metal cable trays with full system appendages.
- The drop-offs to all different points of utilization shall be conduit. Bushed conduit shall be used wherever possible.
- The tray system construction shall be secure and prevent inadvertent access by unauthorized parties.
- The tray system shall have suitable strength and rigidity to provide adequate support for all the contained cables.
- The tray system shall include a means to ventilate the enclosed cables, so the heat generated by the cables can be safely dissipated.
- The tray system shall include barriers to segregate cables of different systems and voltage ratings.
- The tray system shall provide adequate cross-sectional area to permit neat alignment of the cables and avoid crossing or twisting.

Tray systems may be provided in lieu of conduit where LV power and multi-conductor control cables are routed within electrical rooms, mechanical rooms, train control rooms, and so forth. Tray systems shall not be used for installation of medium voltage wires and cables in any locations, nor shall they be used for installation of any wires and/or cables within a tunnel environment.

17.14.5 Ductbanks and Underground Structures

The design of underground ductbanks associated with new electrical utility services (outside the Authority's right-of-way) shall comply with the design requirements of the local electric utility service provider. The design of all other underground ductbanks and associated structures shall comply with the NEC, CEC, and California Public Utility Commission GO 128.

The design of underground ductbanks and associated structures shall be carefully coordinated with other underground utilities and/or structural foundations to assure safe access within the Authority's right-of-way.

Duct banks shall be configured as required at the specific location. Manholes, pull boxes, junction boxes and cable vaults shall be spaced for ease of cable pulling, and shall meet applicable codes and operational requirements, without exceeding cable pulling tensions. The design must be carefully coordinated with underground utilities to assure safe access within the Authority's right-of-way.

Conduit transitions shall be provided when changing from one cable trough location or configuration to another and to provide conduit access from the cable trough to system wayside facilities.

Underground ductbanks shall be sloped toward the adjacent underground structure (e.g., vault, manhole, or box) from which water may be drained or pumped. Underground structures shall be equipped with sump area for drainage by gravity or application of portable or fixed pumps as required.

Vault and/or manhole spacing shall not exceed 500 feet.

Vaults and manhole access covers and ladders shall conform to Cal/OSHA requirements.

Interior length, width, and depth of vaults and manholes shall be sufficient for cable pulling and splicing and for cable expansion and contraction.

The design of vaults and manholes shall incorporate the following features:

- Non-metallic racks or fiberglass cable support insulators, which are spaced to avoid excessive weight or pressure on the cable insulation
- Cable pulling hooks
- Grounding provisions

Refer to the *Structures* chapter for additional requirements pertaining to loading considerations for undertrack ductbanks.

17.14.6 Raceway Systems and/or Cable Trough for the Core Systems

Core Systems include the traction electrification system, automatic train control and system communications and facility communication systems.

Refer to the *Traction Power Supply System*, *Automatic Train Control*, and *Communications* chapters for raceway system requirements for the Core Systems.

Refer to *TBD* chapter for raceway system requirements for the facility communication systems.

Trackside interbuilding power cables associated with the FPS shall not be routed in raceway systems and/or the cable troughs associated with the Core Systems and/or facility communication systems.

17.14.7 Conduits within Reinforced Structures

Conduit spacing, within load bearing structures, shall comply with the requirements of the American Concrete Institute code.

Conduit routing and reinforcement steel designs shall be coordinated to avoid conflicts.

17.14.8 Conduits Routed Under the Track

Unless otherwise specified, all conduits routed under the tracks shall be protected by encasement within reinforced steel concrete. The design of the encased conduits shall consider the loading conditions associated with the trackwork and substructure.

Refer to the *Structures* chapter for track loading conditions.

Refer to the *Utilities* chapter for minimum under track vertical clearance requirements.

17.15 Wiring/Cabling Systems

All conductors shall be enclosed in conduit, tray, and/or raceway.

All wires and cables shall be protected from mechanical impact, heat, or fire by any of the following:

- Suitable embedment or encasement
- Routing external to the interior of a tunnel environment
- Routing within exposed galvanized rigid steel conduit, located clear of the static and dynamic envelopes of the Rolling Stock, and fixed equipment envelope
- Physical diversity in wire/cable routing
- Use of listed fire-resistive cable systems

Wires and/or cables associated with the normal, backup, and emergency power supply sources shall be routed in physically separate raceway systems (i.e., conduit, trays, troughs, boxes) such that the wires and/or cables of more than one power source shall not be damaged by the same localized impact or heat source.

The wire and cable specifications shall be suitable for the intended working environment and comply to the requirements specified in NFPA 130.

Minimum size of power conductors shall be AWG No. 12. Minimum size of control wires shall be AWG No. 14.

Temperature ratings of all wires and cables shall be not less than 90 degrees Celsius.

Insulated cables shall be appropriate for the voltage level and readily available sizes shall be used on the CHSTP.

The number and size of cables in a particular circuit shall be determined to provide adequate capacity, acceptable voltage drop and system fault level.

Insulated cables of different voltage classes shall not occupy the same conduit, tray, junction/pull box, manhole or vault.

Refer to the *Traction Power Supply System*, *Automatic Train Control*, and *Communications* chapters for requirements pertaining to associated cable infrastructure.

17.15.1 Tunnels

Field wires and cables (except exposed bare ground conductors) installed in tunnel environments (including portals, tunnels, cross passages, access/egress shafts, ventilation structures, sump pump structures) shall have insulation ratings based upon the intended working environment and shall be in compliance with the NEC, CEC, and NFPA 130. Unless otherwise approved by the Authority, all factory wiring within trackside-mounted equipment enclosures shall comply with NFPA 130.

All wires and cables shall pass the flame propagation criteria of IEEE 383 and have a minimum circuit time of 5 minutes in the flame test of IEEE 383.

All wires and cables in assessable enclosures/boxes shall be completely fireproofed (2 hours minimum).

17.15.2 Color Coding

All FPS and LS conductors shall be color coded by outer jacket or by vinyl tape according to the following requirements:

- Grounding conductor – Green
- 120/208 V ac ungrounded conductors – a. black; b. red; and c. blue
    - Grounded conductor (Neutral) – white or natural grey
- 120 V dc – red (positive); black (negative)
- 277/480 V ac ungrounded conductors – a. brown; b. orange; c. yellow or purple
    - Grounded conductor (Neutral) – white or natural grey
- HV 3-ph conductors – red, black, and blue, and mark with phase letter

Multi-conductor control/signaling cables shall be color coded in accordance with ICEA Method 1, K-2.

17.16 Identification Requirements (Equipment, Conductors, Conduit, Tray)

17.16.1 Equipment

Each piece of electrical equipment shall be numbered according to the number of the feeder circuit breaker (except termination cabinets, which shall be numbered sequentially), and the numbering shall be reflected on all applicable design and record drawings.

Equipment numbering shall be preceded by letter designations as follows:

Table 17-5: Equipment Numbering

1	Switchboard	A
2	Power Panelboard	P
3	Lighting Panelboard, 480/277 V	L
4	Facility Power Panel, 208/120 V	LA
5	LV Transformer	LVX
6	Local Control Panel	LCP
7	Emergency Walkway Lighting Control Panel	EWLCP
8	Disconnect Switch	Z
9	Motor	M
10	Motor Starter	MS
11	LV Motor Control Center	MCC
12	Intermediate Termination Cabinet	ITC
13	Automatic Transfer Switch	ATS
14	Manual Transfer Switch	MTS
15	Generator	G
16	Uninterruptible Power Supply	UPS
17	Unit Substation	US
18	HV Switchgear	HVSG
19	HV Transformer	HVX
20	HV Motor Control Center	HVMCC

Prefix all electrical equipment with "E" followed by the equipment designation to indicate that power originates from the emergency standby generator, UPS, and/or dc battery system. The equipment identifier shall be reflected on all applicable design and record drawings.

17.16.2 Manholes, Handholes, Vaults and Boxes

All manholes, handholes, vaults, boxes, and so forth shall be identified by a 7-character reference designator: 4 letters followed by a 3-digit number. The 4 letters depend upon the electrical system as follows:

Table 17-6: Manholes, Handholes, Vaults and Boxes

1	MV (i.e., 12 kV and above) Facility Power	MVFPXXX
2	Tunnel Ventilation (4.16 kV) Facility Power	TVFPXXX
3	LV (480 V and below) Facility Power	LVFPXXX

The 3 digits shall increase sequentially, beginning with 001. The manhole, handhole, vault, and/or box identifier shall be reflected on all applicable design and record drawings.

17.16.3 Conduit/Tray

All conduit/tray shall be identified by an 8-character reference designator and depend upon the electrical system as follows:

Table 17-7: Conduit/Tray

1	MV (i.e., 12 kV and above) Facility Power	MVFPXXXX
2	Tunnel Ventilation (4.16 kV) Facility Power	TVFPXXXX
3	LV (480 V and below) Facility Power	LVFPXXXX

The 4 digits shall increase sequentially, beginning with 0001. Interfacility conduit numbering shall be coordinated. The conduit/tray identifier shall be reflected on all applicable design and record drawings.

Interior raceways and tray systems shall be identified. Lettering shall be printed. Markers shall be placed on all exposed or accessible raceways and tray system within 18 inches of raceway/tray termination, wherever raceway and tray system enter or leave concealed space, and every 50 feet along raceway and trays.

The following conventions shall apply:

- Power and lighting raceways and tray systems shall be identified as to the system Line to Line and Line to Ground voltages.
- Emergency power supply system raceways shall be identified “Emergency Power” in addition to system voltage.
- Grounding raceways shall be identified “Ground.”

- Empty raceways shall be identified as "Spare."

Tray systems that house cabling of different subsystems shall be identified by the highest-rated voltage of the cables contained within it.

Conduits within ductbanks shall be identified at all locations where the conduits stub-up and/or into manholes. Identifiers shall be non-conductive, permanent and follow the convention specified above.

17.16.4 Conductors

All conductors shall be identified by an 8-character reference designator and depend upon the electrical system as follows:

Table 17-8: Conductors

1	MV (i.e., 12 kV and above) Facility Power	MVFPXXXX
2	Tunnel Ventilation (4.16 kV) Facility Power	TVFPXXXX
3	LV (480 V and below) Facility Power	LVFPXXXX

The 4 digits shall increase sequentially, beginning with 0001. Interfacility conductor numbering shall be coordinated. The conductor identifier shall be reflected on all applicable design and record drawings.

All conductors shall be identified within 1 foot of the termination point and at all vaults, manholes, pull boxes, junction boxes, and so forth. The identifier shall be non-conductive, permanent and specify the termination details that correspond to the associated termination hardware.

17.16.5 Identification Requirements for the Core Systems and Facility Communication Systems

Refer to the *Traction Power Supply System*, *Automatic Train Control*, *Communications and Facility Communications* chapters for identifier requirements associated with the Core Systems.

Refer to *TBD* chapter for identifier requirements associated with the facility communication systems.

17.17 Electrical Discrete and Serial I/O Point Requirements

All control, alarm, and indication functions shall be available locally and remotely at the Operations/Regional Control Center, passenger stations, Heavy Maintenance Facility, Terminal Layup/Storage and Maintenance Facilities, and right-of-way Infrastructure Facilities. Summary alarms of equipment failures and equipment status indications shall be annunciated at the

Operations/Regional Control Center. Refer to the *Supervisory Control and Data Acquisition Subsystems* chapter for SCADA requirements and *TBD* chapter for the Building Automation System (BAS) requirements.

All discrete and serial input/output (I/O) point designations shall be prefixed with the facility and equipment designations. Refer to *TBD* chapter for facility designation requirements

The FPS equipment/power sources that need to be monitored and/or controlled shall include, but not be limited to, the following:

- All power sources from the electric utility service provider and the traction electrification system
- All HV circuit breakers
- All HV transformers
- All HV motor control centers
- All automatic transfer switches
- All main and tie circuit breakers at 480 V switchboards and/or unit substations
- All emergency standby generators, uninterruptable power source equipment and dc battery system equipment
- Facility lighting control panels
- Tunnel and/or trench lighting circuits
- Local controls within an electrical room activated.

The design of the FPS equipment shall include all necessary equipment, termination blocks, termination hardware, factory wiring, etc. to interface to the SCADA system and the BAS.

17.18 Temporary Power and Lighting

Temporary power and lighting shall be designed and provided for the CHSTP. This design of the temporary power and lighting shall be complete, and shall conform to the NEC, CEC, NFPA 130, and all other applicable electrical and safety codes/orders.

17.19 Grounding, Bonding and Lightning Protection

Refer to the *Grounding and Bonding Requirements* chapter for requirements.

17.20 Fire Detection System

Refer to *TBD* chapter for requirements.

17.21 Vehicular Traffic Management System

Refer to *TBD* chapter for requirements.

17.22 Facility Communication Systems

Refer to *TBD* chapter for requirements.

17.23 Spares

The following spares requirements shall be incorporated into the design of the FPS:

- The design of the FPS shall include electrical distribution capacity, space for future circuit breakers, and rough-in raceway systems to permit future equipment placements in accordance with the Authority's requirements as specified in TBD. Rough-in raceway systems shall be planned and installed in the same fashion as circuits provided under this contract so that when the future equipment is installed, surface-mounted raceway can be avoided.
- HV switchgear, unit substations, switchboards, HV and LV transformers, and panelboards shall be equipped with a minimum of 25 percent spare circuits and bus capacity. Standard size equipment shall be used.
- The design of the Interface Termination Cabinet shall include at least 25 percent spare termination hardware.
- At least 25 percent or 1 spare duct (whichever is greater) per voltage level/system shall be provided in all interbuilding underground ductbank runs.
- At least 25 percent or 1 spare conduit (whichever is greater) per voltage level/system shall be provided in each conduit run.

Appendix 17.A: Minimum Lighting Levels

Facility	ROOM/AREA	LIGHTING LEVELS		LIGHTING TYPE
		AVERAGE MAINTAINED (LUX)	AT (FT)	
At-Grade Passenger Station	- PLATFORM (EDGE, UNCOVERED)	200	0	MH
	- PLATFORM (GENERAL, UNCOVERED)	100	0	MH
	- PLATFORM (EDGE, UNDER CANOPY COVER)	200	0	MH/FLR
	- PLATFORM (GENERAL, UNDER CANOPY COVER)	100	0	MH/FLR
	- UNDER PLATFORM UTILITY CHASES	10	V.@ 3.0	HPS
	- STATION AGENTS BOOTH	150	2.5	FLR
	- CONCOURSE	150	0	MH/FLR
	- MEZZANINE	150	0	MH/FLR
	- FARE GATES	200	0	MH/FLR
	- VENDING MACHINE AREA	200	0	MH/FLR
	- PATRON WAITING AREA	250	0	MH/FLR
	- CONCESSIONS (IF ANY)	200	0	MH/FLR
	- ESCALATORS, STAIRWAYS AND PASSAGEWAYS	100 – 150	TREAD – ENTRANCE TO	MH/FLR
	- ELEVATORS	100	0	CFL
	- WALKWAYS/CORRIDORS	150	0	FLR
	- CONNECTIONS TO PUBLIC WALKWAYS	150	0	FLR
	- RAMPS LEADING TO WALKWAYS	150	0	FLR
	- RESTROOMS	200	0	FLR
	- OFFICES/STAFF ROOMS	300	2.5	FLR
	- STORAGE ROOMS	100	0	FLR
	- CLOSETS	100	0	FLR
	- TRASH ROOMS	100	0	FLR
	- BIKE LOCKER AREA	200	0	FLR
	- BAGGAGE STORAGE AREA	200	0	FLR

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	- JANITORIAL ROOMS	200	0	FLR
	- VAULT AND PIT AREAS	300[1]	0	FLR
	- TELCO ROOM	250	0	FLR
	- ELECTRICAL ROOMS	250	0	FLR
	- TRAIN CONTROL/COMMUNICATIONS ROOM	500	0	FLR
	- BATTERY ROOMS	200	0	MH/HPS
	- EMERGENCY STANDBY GENERATOR ROOM	200	0	FLR
	- ESCALATOR CONTROL ROOMS	100	0	FLR
	- ELEVATOR MACHINE ROOMS	100	0	FLR
	- HVAC ROOMS	250	0	FLR
	- CONDENSER ROOMS	100	0	FLR
	- VALVE ROOMS	100	0	FLR
	- SECURITY ROOMS	250	0	FLR
	- ROOF LIGHTING	10	0	HPS
	- PASSENGER STATION EXTERIOR	50	V. ON SURFACE	MH
Elevated Passenger Station	- PLATFORM (EDGE, UNCOVERED)	200	0	MH
	- PLATFORM (GENERAL, UNCOVERED)	100	0	MH
	- PLATFORM (EDGE, UNDER CANOPY COVER)	200	0	MH/FLR
	- PLATFORM (GENERAL, UNDER CANOPY COVER)	100	0	MH/FLR
	- UNDER PLATFORM UTILITY CHASES	10	V. @ 3.0	H[S
	- STATION AGENTS BOOTH	150	2.5	FLR
	- CONCOURSE	150	0	MH/FLR
	- MEZZANINE	150	0	MH/FLR
	- FARE GATES	200	0	MH/FLR
	- VENDING MACHINE AREA	200	0	MH/FLR
	- PATRON WAITING AREA	250	0	MH/FLR
	- CONCESSIONS (IF ANY)	200	0	MH/FLR
	- ESCALATORS, STAIRWAYS AND PASSAGEWAYS	100-150	TREAD-ENTRANCE TO	MH/FLR
	- ELEVATORS	100	0	CFL
	- WALKWAYS/CORRIDORS	150	0	FLR

	- CONNECTIONS TO PUBLIC WALKWAYS	150	0	FLR
	- RAMPS LEADING TO WALKWAYS	150	0	FLR
	- RESTROOMS	200	0	FLR
	- OFFICES/STAFF ROOMS	300	2.5	FLR
	- STORAGE ROOMS	100	0	FLR
	- CLOSETS	100	0	FLR
	- TRASH ROOMS	100	0	FLR
	- BIKE LOCKER AREA	200	0	FLR
	- BAGGAGE STORAGE AREA	200	0	FLR
	- JANITORIAL ROOMS	200	0	FLR
	- VAULT AND PIT AREAS	300[1]	0	FLR
	- TELCO ROOM	250	0	FLR
	- ELECTRICAL ROOMS	250	0	FLR
	- TRAIN CONTROL/COMMUNICATIONS ROOM	250	0	FLR
	- BATTERY ROOMS	200	0	MH/HPS
	- EMERGENCY STANDBY GENERATOR ROOM	200	0	FLR
	- ESCALATOR CONTROL ROOMS	100	0	FLR
	- ELEVATOR MACHINE ROOMS	100	0	FLR
	- HVAC ROOMS	250	0	FLR
	- CONDENSER ROOMS	100	0	FLR
	- VALVE ROOMS	100	0	FLR
	- SECURITY ROOMS	250	0	FLR
	- ROOF LIGHTING	10	0	HPS
	- PASSENGER STATION EXTERIOR	50	V. ON SURFACE	MH
Exterior Passenger Loading/Circulation Areas/Other Areas Adjacent To The Passenger Station	- BUS LOADING/UNLOADING	75	0	MH
	- BUS LOOPS	25	0	MH
	- PATRON LOADING /UNLOADING	75	0	MH
	- KISS AND RIDE	50	0	MH
	- PLAZA (AT STATION ENTRANCES)	30	0	MH
	- PLAZA	25	0	MH

	- PEDESTRIAN WALKWAYS(OPEN)	30	V. @ 5.0	MH
	- OVERTRACK PEDESTRIAN WALKWAY BRIDGES	100	0	FLR
	- UNDERPASSES	100	0	FLR
	- LANDSCAPING AREAS	ACCENT	0	AS REQ.
Parking Lots	- CIRCULATION ROADWAY LIGHTING	30	0	HPS
	- PEDESTRIAN WALKWAYS	30	0	MH
	- PARKING SPACES	25	0	HPS
Parking Structures	- CIRCULATION ROADWAY LIGHTING	50	V. @ 5.0	HPS
	- PEDESTRIAN WALKWAYS	75	V. @ 5.0	MH
	- STAIRWAYS	100	TREADS	FLR
	- ELEVATORS	100	0	CFL
	- PARKING SPACES	50	V. @ 5.0	HPS
	- ELECTRICAL ROOMS	250	0	FLR
	- ELEVATOR MACHINE ROOMS	100	0	FLR
	- MECHANICAL ROOMS	250	0	FLR
	- BATTERY ROOMS	100	0	HPS
	- PARKING STRUCTURE EXTERIOR	50	V. ON SURFACE	MH
Heavy Maintenance Facility	TBD	TBD	TBD	TBD
Terminal Layup/Storage And Maintenance Facility	TBD	TBD	TBD	TBD
Maintenance-of-Infrastructure Maintenance Facility	TBD	TBD	TBD	TBD
Operations Control Center	- CENTRAL CONTROL ROOM	250	0	FLR
	- OFFICES/STAFF ROOMS	300	2.5	FLR
	- MEETING/TRAINING ROOMS	300	2.5	FLR
	- LUNCH/BREAK ROOM	250	2.5	FLR
	- STORAGE ROOMS	100	0	FLR
	- TELECOMMUNICATIONS COMPANY ROOM	250	0	FLR
	- ELECTRICAL ROOMS	250	0	FLR
	- TRAIN CONTROL/COMMUNICATIONS ROOM	250	0	FLR

	- BATTERY ROOMS	200	0	HPS
	- RESTROOMS			
Portal Facility	- ACCESS ROADWAY LIGHTING	20	0	HPS
	- EMERGENCY VEHICLE ASSEMBLY AND TURNAROUND AREA	50	0	HPS
	- RESCUE AREA/PASSENGER ASSEMBLY AREA	50-100[2]	0	MH
	- HELICOPTER LANDING PAD	50[3]	0	MH
	- PARKING	10	0	HPS
	-EMERGENCY EGRESS WALKWAYS	20	V. @ 5.0	MH
	- STAIRWAYS	100	TREADS	FLR
	- EMERGENCY COMMAND POST	50	0	MH
	- ELECTRICAL ROOMS/YARDS	250	0	MH
	- TRAIN CONTROL/COMMUNICATIONS ROOM	250	0	MH
	- BATTERY ROOM	200	0	HPS
	- EMERGENCY VENTILATION FAN ROOM	10	0	FLR
	- MECHANICAL CONTROL ROOMS	250	0	FLR
	- RESTROOMS	200	0	FLR
	- EMERGENCY STANDBY GENERATOR SITE	50	0	MH
	- PORTAL FACILITY EXTERIOR	50	0	MH
Mid-Tunnel Ventilation Structures	- ACCESS ROADWAY LIGHTING	20	0	HPS
	- EMERGENCY VEHICLE ASSEMBLY AND TURNAROUND AREA	50	0	HPS
	- RESCUE AREA/PASSENGER ASSEMBLY AREA	500-100[2]	0	MH
	- HELICOPTER LANDING PAD	50[3]	0	MH
	- PARKING			
	- EMERGENCY EGRESS WALKWAYS	20	V. @ 5.0	MH
	- STAIRWAYS	100	TREADS	FLR
	- EMERGENCY COMMAND POST	50	0	MH
	- ELECTRICAL ROOMS/YARDS	250	0	MH
	- TRAIN CONTROL/COMMUNICATIONS ROOM	250	0	MH

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	- BATTERY ROOM	200	0	HPS
	- EMERGENCY VENTILATION FAN ROOM	10	0	FLR
	- MECHANICAL CONTROL ROOMS	250	0	FLR
	- RESTROOMS	200	0	FLR
	- EMERGENCY STANDBY GENERATOR SITE	50	0	HPS
	- MID-TUNNEL VENTILATION STRUCTURE EXTERIOR	50	0	MH
Emergency Access Shafts	- ACCESS ROADWAY LIGHTING	20	0	HPS
	- EMERGENCY VEHICLE ASSEMBLY AND TURNAROUND AREA	50	0	HPS
	- RESCUE AREA/PASSENGER ASSEMBLY AREA	50-100[2]	0	HPS
	- HELICOPTER LANDING PAD	50[3]	0	MH
	- PARKING	10	0	MH
	- EMERGENCY EGRESS WALKWAYS	20	V. @ 5.0	MH
	- STAIRWAYS	100	TREADS	FLR
	- ELECTRICAL ROOMS/YARDS	250	0	FLR
	- TRAIN CONTROL/COMMUNICATIONS ROOM	250	0	FLR
	- BATTERY ROOM	200	0	HPS
	- MECHANICAL CONTROL ROOMS	250	0	FLR
Sump Pumps (At-Grade)	- ACCESS ROADWAY LIGHTING	20	0	HPS
	- SITE LIGHTING	50	0	HPS
	- ELECTRICAL ROOMS	250	0	FLR
	- ROOM LIGHTING	200	0	FLR
Sump Pumps (Tunnel)	- ROOM LIGHTING	200	0	FLR
Standalone Traction Power Facilities		20	0	MH
	- PEDESTRIAN WALKWAYS	30	V. @ 3.0	MH
	- SITE/PERIMETER/SECURITY LIGHTING	10	V. @ 5.0	HPS
	- EXTERIOR LIGHTING AT PRE-ENGINEERED ENCLOSURE DOORWAYS	10	0	MH
	- INTERIOR LIGHTING AT PRE-ENGINEERED ENCLOSURES	150	0	FLR
Stand-alone Train		20	0	HPS

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Control/Communication Huts	- PEDESTRIAN WALKWAYS	30	V. @ 5.0	MH
	- SITE/PERIMETER/SECURITY LIGHTING	10	V. @ 5.0	HPS
	- EXTERIOR LIGHTING AT PRE-ENGINEERED ENCLOSURE DOORWAYS	10	0	MH
	- INTERIOR LIGHTING AT PRE-ENGINEERED ENCLOSURES	150	0	FLR

Notes:

1. Maintenance facilities illuminations levels shall depend upon the task to be performed.
2. 50 lux under normal operations and 100 lux during an emergency.
3. Proper aviation lighting shall meet FAA requirements.

Abbreviations: V – Vertical, AVG – Average, REQ – Required, FT – Feet, MH – Metal Halide, HPS – High Pressure Sodium, FLR – Fluorescent, CFL – Compact Fluorescent Lamp

Chapter 18

Fire Protection

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Revision	Date	Description
0	02 Mar 12	Initial Release, R0

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18 Fire Protection (TBD)

TBD. This topic will be included in a future revision of the Design Criteria.

Chapter 19

Building Automation and Management Systems

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Revision	Date	Description
0	02 Mar 12	Initial Release, R0

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19 Building Automation and Management Systems (TBD)

TBD. This topic will be included in a future revision of the Design Criteria.

Chapter 20

Traction Power and Supply System

HSR 13-06 - EXECUTION VERSION

Revision	Date	Description
0	02 Mar 12	Initial Release, R0
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Acronyms

AT	Autotransformer
ATC	Automatic Train Control
CHSTP	California High-Speed Train Project
CPUC	California Public Utility Commission
HST	High-Speed Train
HV	High voltage
IEC	International Electrotechnical Commission
IEEE	Institution of Electrical and Electronics Engineers
MOD	Motor Operated Disconnect Switch
N.C.	Normally Closed
N.O.	Normally Open
NEC	National Electric Code
NEMA	National Electrical Manufacturers Association
NESC	National Electrical Safety Code
NF	Negative Feeder
NFPA	National Fire Protection Association
O&M	Operations and Maintenance
OCC	Operations Control Center
OCS	Overhead Contact System
PS	Paralleling Stations
RCC	Regional Control Center
rms	root mean square
SCADA	Supervisory Control and Data Acquisition
SS	Traction Power Substations
SWS	Switching Stations
TES	Traction Electrification System
TPF	Traction Power Facilities
TPS	Traction Power Supply System
WPC	Wayside Power Control Cubicles

20 Traction Power Supply System

20.1 Scope

The scope of this chapter includes the main design requirements for the Traction Power Supply System (TPS) and associated site works for the Project, which is based upon a 2x25 kilovolt (kV) autotransformer feed configuration. The design of the TPS and associated site works shall be coordinated with the following:

- The requirements of the power supply utility companies (both investor-owned and municipal utility companies) providing electrical power to the system
- The requirements of the state and local jurisdictions in which the Traction Power Facilities (TPF) are located
- The technical and operational parameters and requirements of the system (e.g., track work, Overhead Contact System (OCS), rolling stock, operations, maintenance, train control system, communications system, electromagnetic compatibility, etc.)

This document shall be read in conjunction with the TPS-related Standard and Directive Drawings and other procurement documents.

Refer to the *Facility Power and Lighting Systems* chapter for additional design requirements for electrical equipment. In case of a conflict between requirements specified in this chapter and the *Facility Power and Lighting Systems* chapter, the requirements of this chapter shall prevail.

20.2 Regulations, Codes, Standards, and Guidelines

Refer to the *General* chapter for requirements pertaining to regulations, codes, and standards.

- American Railway Engineering and Maintenance-of-Way Association (AREMA)
  - AREMA Manual for Railway Engineering, Volume 3 Infrastructure and Passenger, Chapter 33 Electric Energy Utilization
- California Code of Regulations (CCR)
  - Title 8 – Occupational Safety and Health Act Standards
  - Title 19 – Public Safety
- California Building Standards Code (CBSC), Title 24 of California Code of Regulations (CCR) –
  - Part 2 – California Building Code
  - Part 3 – California Electrical Code

  - Part 6 – California Energy Code
  - Part 9 – California Fire Code
- California Public Utility Commission (CPUC) General Orders (GOs)
  - GO 95 – Overhead Electric Line Construction
  - GO 128 – Construction of Underground electric Supply and Communications System
- European Standards (EN for European Norms)
  - EN 50121-1 – Railway applications – Electromagnetic Compatibility
  - EN 50122-1 – Protective Provisioning Relating to Electrical Safety and Earthing
  - EN 50124-1 – Railway applications – Insulation Coordination
  - EN 50124-2 – Railway applications – Overvoltages and Related Protection
  - EN 50152 – Railway Applications–Fixed Installations–Particular Requirements for ac Switchgear Part 1: Single-phase circuit-breakers with U_m above 1 kV Part 2: Single-phase disconnectors, earthing switches and switches with U_m above 1 kV.
  - EN 50160 – Voltage Characteristics of Electricity Supplied by Public Distribution Systems
  - EN 50163 – Railway Applications – Supply Voltages of Traction Systems,
  - EN 50329 – Railway Applications – Fixed Installations – Traction Transformers
  - EN 50388 - Railway Applications – Power Supply and Rolling Stock – Technical Criteria for the Coordination Between Power Supply (Substation) and Rolling Stock to achieve Interoperability
- Insulated Cable Engineers' Association (ICEA) Standards
  - ICEA S-95-658/NEMA WC70 – Standard for Nonshielded Power Cables Rated 2000 Volts or Less for the Distribution of Electrical Energy
- International Electro-technical Commission (IEC) Standards
  - IEC 60056 – A.C. High Voltage Circuit Breakers
  - IEC 60076 – Power Transformers
  - IEC 60099-4 – Surge Arresters
  - IEC 60298 – A.C. Metal-Enclosed Switchgear and Controlgear for Rated Voltages Above 1 kV and Up to and Including 52 kV
  - IEC 60694 – Specifications Common for High Voltage Switchgear and Controlgear Standards
  - IEC 62271 – High-Voltage Switchgear and Control Gear
- Institution of Electrical and Electronics Engineers (IEEE) Standards

- IEEE 80 – IEEE Guide for Safety in AC Substation Grounding
- IEEE 242 – IEEE Recommended Practice for Protection and Coordination of Power Systems
- IEEE 485 – IEEE Recommended Practice for sizing Large Lead Storage Batteries for Generating Stations and Substations
- IEEE 519 – IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems
- IEEE 980 – IEEE Guide for Containment and Control of Oil Spills in Substations
- IEEE 1189 – IEEE Guide for Selection of Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications
- IEEE 1427 – IEEE Guide for Recommended Electrical Clearances and Insulation Levels in Air-Insulated Electric Power substations
- IEEE C2 – National Electrical Safety Code
- IEEE C9.1 – Standard for Insulation Coordination
- IEEE C37.04 – Rating Structure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis
- IEEE C37.2 – Electric Power System Device Function Numbers and Contact Designations
- IEEE C37.20.2 – IEEE Standard for Metal-Clad Switchgear
- IEEE C37.20.4 – IEEE Standard for Indoor AC Switches (1 kV-38 kV) for Use in Metal-Enclosed Switchgear
- IEEE C37.30 – IEEE Standard Requirements for High-Voltage Switches
- IEEE C37.90 – IEEE Standard for Relays and Relay Systems Associated with Electric Power Apparatus
- IEEE C57.12.00 – Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers
- IEEE C57.12.10 –American National Standards for Transformers – 230 kV and Below 833/958 through 8,333/10,417 kVA, Single-Phase, and 750/862 through 60,000/80,000/100,000 kVA Three-Phase, without Load Tap Changing; and 2,750/4,687 Through 60,000/80,000/1000,000 kVA with Load Tap Changing – Safety Requirements
- IEEE C57.12.80 – Standard Terminology for Power and Distribution Transformers
- IEEE C57.91 – Guide for Loading Mineral-Oil Immersed Transformers (Including Corrigendum 1)
- IEEE C62 – IEEE Surge Protection Standards Collection

- IEEE C62.11 – IEEE Standard for Metal-Oxide Surge Arresters for Alternating Current Power Circuits
- IEEE C80.1 – Rigid Steel Conduit, Zinc Coated
- IEEE C84.1 – Voltage Ratings for Electrical Power Systems and Equipment (60 Hz)
- IEEE Std C95.1 – Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 3 kHz - 300 GHz
- IEEE Std C95.6 – Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0 – 3 kHz

- U.S. Department of Defense (USDOD) Standards
  - 246431 series
- National Electrical Manufacturers Association (NEMA) Standards
  - NEMA 250 – Enclosures for Electrical Equipment (1,000 Volts Maximum)
  - NEMA BU 1 – Busways
  - NEMA FG 1 – Fiberglass Cable Tray Systems
  - NEMA LA 1 – Surge Arresters
  - NEMA PB 1 – Panelboards
  - NEMA PE 5 – Utility Type Battery Chargers
  - NEMA RN1 – Polyvinyl-Chloride (PVC) Externally Coated Galvanized Rigid Steel Conduit and Intermediate Metal Conduit
  - NEMA SG 4 – AC High-Voltage Circuit Breakers
  - NEMA SG 6 – Power Switching Equipment
  - NEMA TC 2 – Electrical Polyvinyl Chloride (PVC) Tubing and Conduit
  - NEMA TC 14 – Reinforced Thermosetting Resin Conduit (RTRC) and Fittings
  - NEMA TR 1 – Transformers, Regulators and Reactors
  - NEMA VE 1 – Metallic Cable Tray Systems
  - NEMA WC 70 – Nonshielded 0-2 kV Cables (ICEA S-95-658)
  - NEMA WD 1 – General Color Requirements for Wiring Devices
- National Fire Protection Association (NFPA) Codes and Standards
  - NFPA 70 – National Electrical Code
  - NFPA 101 – Life Safety Code
  - NFPA 110 – Standard for Emergency and Standby Power Supply Systems
  - NFPA 130 – Standard for Fixed Guideway Transit and Passenger Railway Systems

  - NFPA 780 – Standard for Lightning Protection Systems
- Underwriters' Laboratories (UL) Publications
  - UL 5 – Surface Metal Raceways and Fittings
  - UL 6 – Rigid Metal Conduit
  - UL 44 – Thermoset-Insulated Wires and Cables
  - UL 50 – Enclosures for Electrical Equipment
  - UL 67 – Panelboards
  - UL 83 – Thermoplastic Insulated Wires and Cables
  - UL 489 – Molded-Case Circuit Breakers, Molded Case Switches and Circuit-Breaker Enclosures
  - UL 651 – Schedule 40 and 80 Rigid PVC Conduit
  - UL 924 – Emergency Lighting and Power Equipment
  - UL 1008 – Transfer Switches
  - UL 1059 – Terminal Blocks
  - UL 1581 – Reference Standard for Electrical Wires, Cables and Flexible Cords

20.3 Overview and General Design Criteria

20.3.1 Traction Electrification System

Traction Electrification System (TES) is the combination of the TPS, OCS, and the traction power return system, together with appropriate interfaces to the TES-related Supervisory Control and Data Acquisition (SCADA) System. It forms a fully functional 2x25 kV ac TPS and provides the traction power to the electrically powered vehicles on the railway line.

20.3.2 Description of Traction Electrification System

Terms used in this chapter include the following:

- Traction Power Supply System (TPS) – TPS is the railway traction distribution network used to provide energy to high-speed electric trains, which comprises three types of TPF (traction power substations, switching station, and paralleling stations) in addition to connections to the OCS and to the traction return and grounding system, and wayside power control cubicles for control and operation of wayside motor operated disconnect switches.
- Traction Power Substations (SS) – An electrical installation where power is received at high voltage and transformed to the voltage and characteristics required at the catenary and negative feeders for the nominal 2x25 kV system, containing equipment such as

transformers, circuit breakers and sectionalizing switches. It also includes the incoming lines from the power supply utility.

- Switching Stations (SWS) – This is an installation where the supplies from two adjacent SS are electrically separated and where electrical energy can be supplied to an adjacent, but normally separated electrical section during contingency power supply conditions. It also acts as a Paralleling Station.
- Paralleling Stations (PS) – An installation that helps boost the OCS voltage and reduce the running rail return current by means of the autotransformer feed configuration. The Negative Feeder (NF) and the catenary conductors are connected to the two outer terminals of the autotransformer winding at this location with the central terminal connected to the rail return system. OCS sections can be connected in parallel at PS locations.
- Traction Power Facilities (TPF) – TPF is a general term that encompasses substations, switching stations, and paralleling stations.
- Traction Power Return System – All conductors including the grounding system for the electrified railway tracks, which form the intended path of the traction return current from the wheel-sets of the traction units to the substations under normal operating conditions and the total return current under fault conditions. The conductors may be of the following types:
  - Running rails
  - Impedance bonds
  - Static wires, and buried ground or return conductors
  - Rail and track bonds
  - Return cables, including all return circuit bonding and grounding interconnections
  - Earth

  and, as a consequence of the configuration of the autotransformer connections, the negative feeders.
- Overhead Contact System (OCS) – OCS comprises the following:
  - The aerial supply system that delivers 2x25 kV traction power from substations to the pantographs of high-speed electric trains, comprising the catenary system messenger and contact wires, stitch wires and hangers, associated supports and structures (including poles, portals, headspans and their foundations), manual and/or motor operated isolators, insulators, phase breaks, conductor termination and tensioning devices, downguys, and other overhead line hardware and fittings.
  - Portions of the traction power return system consisting of the negative feeders and aerial static wires, and their associated connections and cabling.

- Catenary – An assembly of overhead wires consisting of, as a minimum, a messenger wire, carrying vertical hangers that support a solid contact wire (which is the contact interface with operating electric train pantographs), and which supplies power from a central power source to an electrically-powered vehicle, such as a train.
- Messenger Wire – In catenary construction, the OCS Messenger Wire is a longitudinal bare stranded conductor that physically supports the contact wire or wires either directly or indirectly by means of hangers or hanger clips and is electrically common with the contact wire(s).
- Contact Wire – A solid grooved, bare aerial, overhead electrical conductor of an OCS that is suspended above the rail vehicles and which supplies the electrically powered vehicles with electrical energy through roof-mounted current collection equipment - pantographs - and with which the current collectors make direct electrical contact.
- Negative Feeder (NF) – Negative Feeder is an overhead conductor supported on the same structure as the catenary conductors, which is at a voltage of 25 kV with respect to ground but 180° out-of-phase with respect to the voltage on the catenary. Therefore, the voltage between the catenary conductors and the negative feeder is 50 kV nominal. The NF connects successive feeding points and is connected to one terminal of an autotransformer in the TPF via a circuit breaker or disconnect switch. At these facilities, the other terminal of the autotransformer is connected to a catenary section or sections via circuit breakers or disconnects.
- Static Wire – A wire, usually installed aerially adjacent to or above the catenary conductors and negative feeders, that connects OCS supports collectively to ground or to the grounded running rails to protect people and installations in case of an electrical fault. In an ac electrification system, the static wire forms a part of the traction power return circuit and is connected to the running rails at periodic intervals and to the traction power facility ground grids. If mounted aerially, the static wire may also be used to protect the OCS against lightning strikes. It is sometimes termed “aerial ground wire.”
- Electrical Section – This is the entire section of the OCS, which, during normal system operation, is powered from an SS circuit breaker. The SS feed section is demarcated by the phase breaks of the supplying SS and by the phase breaks at the nearest SWS or line end. An electrical section may be subdivided into smaller elementary electrical sections.
- Elementary Electrical Section – The smallest section of the OCS power distribution system that can be isolated from other sections or feeders of the system by means of disconnect switches and/or circuit breakers.
- Rail Potential – Rail Potential is defined as the voltage between running rails and ground occurring under operating conditions when the running rails are utilized for carrying the traction return current or under fault conditions.

20.3.2.1 System Configuration

The TES shall have a 2 x 25 kV autotransformer feed type configuration.

The TES configuration shall utilize Traction Power Substations (SS) with main transformers, and Switching Stations (SWS) and Paralleling Stations (PS), both with autotransformers, which provide 25 kV (nominal) voltage to the catenary with respect to remote ground, and also 25 kV to along-track Negative Feeders (NF) with respect to remote ground. Both of these voltages are 180° out-of-phase with each other; therefore, the catenary is at 50 kV with respect to the NF.

Traction power will be supplied to the trains from wayside TPF through the catenary, which distributes the power to the train pantographs. The pantographs, mounted on the roof of the rolling stock, collect the traction power from the catenary through mechanical contact by running/sliding under the contact wire. The electrical circuit is completed back to the source SS via multiple return paths, including running rails, static wires, ground, and the NF. From the SS—which transform two phases of the high-voltage (HV) (115kV or 230kV as applicable), 3-phase, utility power to the 2x25 kV single-phase power of the autotransformer feed system—the power for the trains will be distributed along the tracks by the OCS. Some of the high-voltage incoming feed points are at 230 kV and some are at 115 kV. Along the open route, the NF shall be bare overhead conductors, one NF per main track, attached to the catenary structures with brackets and insulators. The catenary shall consist of a messenger wire and a contact wire. The contact wire will be suspended from the messenger wire by the means of hangers, and tied electrically to the messenger wire by means of jumper wires. The details of OCS design criteria are presented in the *Overhead Contact System and Traction Power Return System* chapter.

Autotransformers will be provided periodically along the line, interconnecting catenary, NF and rails. The autotransformer turns ratio shall be 2:1 of primary (catenary-to-NF) to secondary (catenary-to-rails) windings, in order to step down the 50 kV distribution voltage between catenary and NF, to 25 kV nominal between catenary and rails, suitable for the trains.

20.3.2.2 TPS Performance Requirements

The TPS, in conjunction with the OCS shall be designed to meet the following performance requirements within the safety parameter listed below:

- The line speed for both the sections of the California High-Speed Train Project (CHSTP) dedicated to very high speed where the maximum operating speed is 220 mph and the maximum design speed is 250 mph.
- The design peak frequency of trains for Phase I, which shall be 12 trains in each direction with 9 trains consisting of 2 trainsets (1,312 feet or 400 m) and 3 trains consisting of 1 trainset (656 feet or 200 m).
- No degradation of train performance in case of single electrical contingency conditions and there shall be no stranding of trains in case of double electrical contingency conditions. See Section 20.7.4, Continuity of Power Supply in Case of Disturbances, for further details.
- The system will support the maximum train current, the tractive effort and braking effort available/permissible at different speeds, the train acceleration/deceleration/adhesion

characteristics, and other relevant parameters of a typical modern high-speed train (HST) system. (*This information shall be provided by the Rolling Stock Contractor.*)

20.3.3 RAMS Requirements

These are specified elsewhere in the contract documents[1]

20.3.4 General Design Requirements

Safety Design – The design of the TPS and associated site works shall incorporate the following principles:

- Avoiding, eliminating, or reducing hazards identified by engineering hazard analysis, through design choices, material selection, or substitution.
- Incorporating fail-safe principles where failures could disable the system, cause human injury, damage to equipment, or inadvertent operation of critical equipment.
- Locating equipment components so that access to them by the required personnel during operation, maintenance, repair, or adjustment shall not require exposure to hazards such as entrapment, chemical burns, electrical shock, cutting edges, sharp points, or toxic atmospheres.
- Providing measures designed to prevent or discourage unauthorized persons from entering hazardous areas. See the *Electromagnetic Compatibility and Interference* chapter for additional requirements.
- All components containing or generating obnoxious, flammable, and harmful gases shall be vented to the outside.
- Cables and wires of different systems and/or high- and low-voltage conductors shall be physically segregated / separated from each other and rated in accordance with the requirements specified in CEC, NEC and IEEE-1100, as applicable.

Product Selection – All prescribed equipment, materials, cables and appurtenances shall be either certified by a nationally recognized testing laboratory, or compliant with relevant ANSI/IEEE, EN or local standards.

- All prescribed equipment, materials, cables and appurtenances shall be designed, constructed and have a "proven track record" of operating within the intended application and operating environment.
- All equipment, materials, cables and appurtenances shall be produced by manufacturers that are regularly engaged (i.e., at least 5 consecutive years) in the production of such products.

[1] This work is on hand. To be confirmed that it has been completed and included in the contract documents.

- All prescribed equipment, materials, cables and appurtenances shall adhere to applicable recommended practices by AREMA.

Uniformity – Equipment enclosures, assemblies, sub-assemblies, and/or components that do not differ in operational, functional, and/or performance characteristics shall be designed so that all components are positioned in the same location and internal wiring is routed between components in a like manner.

Where identical installations exist, the following requirements shall be adhered to (unless site conditions prevent it):

- Equipment enclosures shall be mounted and installed in a like manner.
- Penetrations for conduit, grounding, and access panels shall be located in the same place.
- The location of equipment relative to adjacent equipment shall not differ.
- The routing of conduit, cable tray, and cables between equipment enclosures shall not differ.
- Termination hardware shall be located in like manner.
- Cables and wire terminations shall be located in like manner.

Accessibility and Equipment Arrangement – Working clearances on all sides of equipment shall be provided (per the equipment manufacturer's recommendations, power utility requirements, CEC, NEC and/or NESC); as well as horizontal and vertical clearance for equipment removal, replacement and/or maintenance (without impacting other energized equipment), and door openings/hatches.

Each prefabricated enclosure for 25-kV indoor switchgear shall have adequate area to accommodate the electrical equipment, raceways/cable trays and ancillary components, and personnel, and allow for easy removal and replacement of any equipment item.

All switchgear enclosures shall have front- and rear-access doors and/or removable panels.

Environmental Conditions – The TPS design shall be suitable for the environmental conditions that have been specified in other chapter of this Design Criteria (e.g., the *General, Seismic, Structures, and Facility Power and Lighting Systems* chapters) and in other contract documents.

20.4 Key Design Criteria

20.4.1 Traction Power Substations

General – Based on the results of a traction power study involving load flow analysis, it has been determined that the needs of the project can be served by SS spaced approximately 30 miles apart. The SS locations have been determined in consideration of the results of the load flow simulation analysis, proximity to high-voltage transmission facilities and feasibility of drawing the required HV power, and availability of real estate.

HV Connection Scheme – At each SS, 2 separate 3-phase HV circuits will be drawn from the power utility network. These circuits should be originating from different utility substations, at least from different bus systems. These may be carried on the same transmission towers. Two equally sized HV traction power transformers shall be provided at each SS, with each transformer supplied from a separate incoming circuit. Both transformers shall be energized under normal TES configuration—one of them supplying power to the feed section north of the SS and the other to the section to the south—with the two feed sections separated by a phase-break at the SS. Both HV power transformers shall be individually capable of supplying the full normal load of the SS.

The HV transformers shall be single-phase, with their primary windings connected to two phases of the utility 115 (or 230) kV 3-phase system. The secondary winding of the HV transformer shall either be a single winding with a grounded midpoint connected also to the running rails, or comprise two separate counter-phase secondary windings connected in series, with the common point grounded and connected to the running rails.

For HV transformer details refer to Section 20.9.4 – High-Voltage Transformers.

Impact on the HV Utility Grid – The load imposed by the railway's traction power substations on the electric utility's 3-phase, 115 (or 230) kV system will be single-phase, nonlinear and rapidly variable over time. Since each HV transformer will draw power from only two phases of a 3-phase system, some current and voltage imbalances will inevitably be caused in the HV supply grid. As a rule, the railway load is characterized by three factors:

- Phase unbalance caused by the single-phase nature of the load. Of the current and voltage imbalances, the voltage imbalance is of greater concern, as it affects the power quality of other utility customers.
- Voltage flicker, caused by the highly variable nature of the load.
- Harmonic distortion, produced by the power convertors on the trains.

In order to mitigate the effects of the unbalanced loading, the single-phase connections of the HV transformers shall be alternated from one pair of phases feeding one transformer to a different pair of phases feeding the other transformer at the same SS; the phase connections shall be changed between substations. This will tend to partially balance the load between the three phases regionally.

The TPS design shall address power quality issues, such as voltage imbalance, voltage flicker, and harmonic distortion caused by the railway load on the HV supply system, arising from operation of the HST. The measures shall be subject to approval/concurrence by the Authority.[2]

[2] This aspect of approval/concurrence by the Authority will be moved to another contract document. This aspect can be "self-certified" provided it is captured in the V&V document.

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Configuration and Operational Flexibility – The traction power substation's single-line diagram and reconfiguration capabilities shall be such that in the event of a power loss to one of the incoming 115 (or 230) kV feeder lines, or temporary outage of one of the transformers, or transformer-related equipment, or outage of a 25 kV bus section, the remaining transformer shall be able to supply power to the feed sections north and south of the SS.

The "positive" bus of the SS (the bus supplying power to the catenary) shall be split into two sections interconnected via a normally open (N.O.) motorized tie circuit breaker, with each bus section supplied by a different transformer under normal conditions. Each section of the positive bus shall feed two different catenary electrical sections in normal TES configuration for two main tracks. (Similar requirements apply to four main track sections.) The "negative" bus of the SS (the bus supplying power to the along-track NF) shall be sectionalized likewise. Tie-breakers of the catenary and the NF buses shall be interlocked with each other so that they open and close together; these shall be, in effect, double-pole circuit breakers. The tie-breakers shall also be interlocked with their associated disconnect switches and the main transformer circuit breakers to prevent inadvertent bridging of 2 incoming supplies.

The outer terminals of the secondary winding of each HV transformer shall be connected to the positive and negative buses (the bus sections corresponding to the particular transformer) through a double-pole circuit breaker. The positive and negative buses in turn shall be connected to the catenary and NF, respectively, through single-pole circuit breakers and in-series connected no-load motorized disconnect switches.

Jumper-type motorized, N.O., load-break disconnect switches shall also be provided, connected between each pair of in-phase, same-side, single-pole circuits to allow for one 25 kV circuit to feed both track sections under emergency conditions of feed extension because of complete failure of any SS. Furthermore, N.O. trackside, motorized, load-break switches shall be installed at the substation's phase break, to provide for electrical continuity in emergency conditions between the catenary and NF, respectively, on either side of the phase break. The flexibility and re-configuration capability of the single line diagram of the SS on the 50/25 kV side shall be such that a loss of 1 single-pole circuit breaker, or disconnect switch, or interconnecting cable still allows the SS to feed the whole feed zone of the SS without having to de-energize one of the HV transformers. See Standard and Directive Drawings for details for this as well as following subsections.

20.4.2 Switching Stations

General – The SWS is a facility interfacing the feeding sections of adjacent SS. This is an installation at which electrical energy can be supplied to an adjacent, but normally separated electrical section during contingency power supply conditions.

Connection – Because the ac voltages on either side of any SWS will be of different phases (or even if these have the same phase sequence, the angular displacement may be different), the SWS shall include a phase break. In normal operations, the phase break shall be open, isolating

the 2 feed sections. Autotransformers (ATs) shall be connected on either side of the phase break, 1 AT per side, serving as the last AT of the respective feed section.

The catenary and NF buses shall be connected in turn to the primary winding terminals of the AT via a double-pole circuit breaker. The AT winding center tap shall be connected to a neutral bus, which shall be locally grounded and connected to the running rails of both tracks (through impedance bonds as required) and to the static wires.

Configuration – The SWS equipment shall include switchgear (25 kV circuit breakers) and motorized disconnect and bypass switches in a configuration that allows isolation of an AT in case of problems, and as required for maintenance. The SWS design shall provide for electrical continuity across the phase break in contingency operations, in the event the SS on one side is out-of-service. In such instances, the SS on the other side of the SWS shall be used to provide power to the sections normally served by the outaged SS. This shall be achieved by interconnecting the catenary and NF on both sides of the SWS, by closing N.O. tie circuit breakers. Furthermore, N.O. trackside, motorized, load-break disconnect switches shall be installed at the SWS phase break, to provide for electrical continuity in emergency conditions between the OCS and NF, respectively, on either side of the phase break. Suitable interlocking shall be provided between the tie-breakers and the phase-break bridging disconnect switches at the SWS with the circuit breakers of adjacent substations to prevent inadvertent bridging of feeds from the 2 substations.

20.4.3 Paralleling Stations

General – The Paralleling Station (PS), known also as an AT station, is a facility featuring an AT as part of the 2x25 kV TES, and associated switchgear and disconnect switches. The PS helps boost the OCS voltage and reduce the running rail return current by means of the autotransformer feed configuration. The AT installed along the line in the PS steps down the 50 kV nominal voltage between catenary and negative feeder to the 25 kV level between catenary and running rails. Similar to the SS, the number and locations of the PS have been determined based on the results of a traction power study, and by taking into account environmental and real estate considerations.

AT Connection – One AT serving all tracks shall be installed at each PS, along with a line-up of medium voltage switchgear containing separate buses for connections to the catenary and NF circuits. The switchgear shall include single-pole 25 kV catenary circuit breakers and NF circuit breakers, and double-pole 50 kV AT circuit breaker. The catenary and NF conductors shall be connected to the switchgear buses via no-load type motorized disconnect switches and the switchgear. The catenary and NF buses shall be connected in turn to the primary winding terminals of the AT via a double-pole circuit breaker. The AT winding center tap shall be connected to a neutral bus, which shall be locally grounded and connected also to the running rails of both tracks (through impedance bonds as required) and to the static wires.

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PS Configuration – The PS shall provide a booster connection to the OCS, without OCS sectionalizing gap. There shall be no sectionalizing of the catenary and NF circuits at the PS. The catenary of each main track shall be connected via single-pole circuit breaker to the catenary bus of the PS. Likewise, the NF wire of each track shall be connected via tap connection and single-pole circuit breaker to the NF bus. For a PS serving only 2 main tracks this configuration results in 4 single-pole circuit breakers overall—2 for the OCS bus and 2 for the NF bus.

20.4.4 Traction Electrification System Sectionalizing Requirements

Main Tracks – The catenary shall be sectionalized between the tracks and longitudinally on the same track along the route in order to limit the extent of an outage zone due to faults or maintenance. Longitudinal sectionalizing of the catenary shall be provided at the SS, SWS, and at all track interlockings and track turnouts. The sectionalizing at the SS and SWS shall be of the phase break type; elsewhere it shall be a regular sectioning gap (insulated overlap or air gap type on the main tracks, with section insulators permitted on crossover and turnout tracks).

At TPF, the sectionalizing gaps shall be provided with N.O. no-load type motorized disconnect switches that can be closed during contingency operations if the catenary on both sides of the sectionalizing gap needs to be electrically continuous.

At track interlockings, the longitudinal sectionalizing gaps shall be provided with normally-closed (N.C.) circuit breakers and/or motorized disconnect switches, which can be opened during contingency operations to isolate a smaller segment of 1 track between adjacent interlockings (contained within an electrical section) or within an interlocking and the adjacent SS or SWS (contained within an electrical section), and permit single-track operations on the other track. At back-to-back crossovers, the sectionalizing arrangement shall be such that the catenary of any track on either side of the interlocking can be isolated selectively.

Concerning the negative phase, two parallel along-track NF shall be provided along the route (1 per main track) regardless of the number of parallel tracks at a given location. Longitudinally, the NF system shall be sectionalized at the SS and SWS.

Power Supply to Sidings and Extra Terminal Tracks – As a rule, the power supply to short segments of track sidings not used for regular train service along the main line shall be derived from the adjacent main track via N.C. no-load type motorized disconnect switch across the sectionalizing gap at the turnout. If the siding has turnouts from the main track at both ends, sectionalizing gaps and switches shall be provided at both ends, with one of the disconnect switches being N.O. and the other N.C. type. Such feeding arrangement shall be used regardless of whether the track siding is close to a TPF or not. At terminals with more than 2 tracks, traction power for the additional tracks shall be derived from the main tracks in similar fashion (i.e., using N.C. motorized disconnect switches across sectionalizing gaps at the turnouts). Both sidings and extra terminal tracks shall be radially fed from the adjoining main track through a

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single connection point. Exceptions to the above rule shall be subject to approval by the Authority.[3]

Overhead Line Switches – The N.O. disconnect switches at sectionalizing gaps at TPF, and the N.C. sectionalizing or power supply switches at track interlockings shall be load-break type, motorized, featuring remote status monitoring and remote control capabilities.

Refer to the *Overhead Contact System and Traction Power Return System* chapter for additional requirements.

20.4.5 Ratings and Configuration for Each Type of Traction Power Facilities

Ratings and configuration for each type of TPF shall be standardized to the extent practical. In general, each SS shall have two 60 MVA power transformers, each SWS shall have two 20 MVA AT and each PS shall have one 20 MVA autotransformer. The locations of the SS and the SWS are fixed because of the location of HV power supply points.

20.4.6 High-Voltage Utility Connections

Different feeding arrangements on the HV side include direct feed from a utility substation or loop-in-loop-out feeding arrangement from its HV transmission network. The specific feeding arrangement at any SS depends on site-specific conditions, the configuration of the power utility company's network at that location, and the policies/procedures of the power utility company.

At some locations, the concerned power utility company is required to install an HV switching station adjacent to the SS location for supplying HV power to the SS. The space requirements for this utility switching station depends upon the HV system voltage, the feeding arrangement and the configuration of the power utility's network, and varies from site to site. These sites have been identified and environmentally cleared. See Section 20.9.23, Real Estate Requirements: Approximate footprints for the Traction Power Facilities, for additional information.

20.4.7 Regenerative Braking

The TPS and the associated OCS shall be designed to permit the use of regenerative braking as a service brake and as an emergency brake.

The use of regenerative braking shall be facilitated by one or more of the following:

- Transfer of braking energy back into the OCS for use by another train(s) that is (are) drawing power from the OCS and is (are) located in the same electrical section as the braking train

[3] This will be a case of "Design Variance."

- Transfer of braking energy back to the power supply utility company's network in case trains in the same electrical section do not draw the full regenerated power
- Provision of rheostatic braking resistors or other electrical energy absorbing units onboard the trains
- Provision of automatic assured receptivity unit braking resistors within TPS substations.

The SS control and protection devices shall be configured to allow regenerative braking.

Trains may continue to use regenerative braking to supply energy to auxiliary loads if the line voltage is higher than 29 kV. The remaining energy shall be dissipated through rheostatic braking.

20.4.8 Power Supply for Rolling Stock Maintenance Facilities

In addition to the traction power substations required for electrification of the main track, four more substations will be required at the rolling stock maintenance facilities proposed in the Central Valley, the San Francisco area, the San Jose – Gilroy area, and the Los Angeles – Anaheim area. These substations will provide power supply for the following:

- Traction Purposes – for operation of trains in the storage yard/siding and maintenance tracks and for feeding auxiliary power to trains standing therein with raised pantographs
- Facility Power Services – for buildings, machinery and plant, illumination, HVAC, water pumps, control power, etc.

The TPS of the maintenance facilities and their yards will be conventional 1x25 kV ac system. It is planned to provide 2 main traction power transformers of 30 MVA each in each facility substation, one supplying the traction load in the facility, and the other acting as 100 percent standby. Refer to the *Facilities Power and Lighting Systems* chapter for design of the facilities power system. Two independent HV circuits will be brought from the power supply utility network at each maintenance facility location—one normally feeding the traction load and the other the facility power load. The substation switchgear and other equipment shall be so configured that either of the incoming HV circuit can feed the traction and facility power loads simultaneously.

Normally, the TPS of the rolling stock facility will be segregated from the traction power supply of the main track. The traction power system design shall provide for suitable and safe interconnection between the 2 adjacent systems under contingency conditions.

20.5 Related Documentation

NOT USED.

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20.6 System Voltage and Frequency

20.6.1 System Voltage

The system voltage (U) shall be the potential at the train's current collector or elsewhere on the catenary, measured between the catenary and the rail return circuit. It shall be the root mean square (rms) value of the fundamental ac voltage and its values shall be as follows (refer to European Standard EN 50163 – 2004: Railway Applications – Supply Voltages of Traction Systems):

- The nominal voltage (U_n), (the designated value for the system voltage) shall be 25 kV.
- The highest permanent voltage (U_{max1}) (the maximum value of the voltage likely to be present indefinitely) shall be 27.5 kV.
- The highest non-permanent voltage (U_{max2}) (the maximum value voltage likely to be present for a limited period of time (as defined below) shall be 29.0 kV.
- The lowest permanent voltage (U_{min1}) (the minimum value of voltage likely to be present indefinitely) shall be 19.0 kV.
- The lowest non permanent voltage (U_{min2}) (the minimum value of voltage likely to be present for a limited period of time (as defined below) shall be 17.5 kV.

20.6.2 Voltage Related Requirements

The following voltage related requirements shall be fulfilled:

- The duration of voltages between U_{min1} and U_{min2} shall not exceed 2 minutes.
- The duration of voltages between U_{max1} and U_{max2} shall not exceed 5 minutes. If voltage between U_{max1} and U_{max2} is reached, it shall be followed by a level below or equal to U_{max1} for an unspecified period. Voltages between U_{max1} and U_{max2} shall only be reached for non permanent conditions such as regenerative braking.
- The voltage at the busbar of the substation at no-load conditions shall be less than or equal to U_{max1}.
- Under normal operating conditions, voltages shall be within the range of $U_{min1} \leq U \leq U_{max2}$.
- Under abnormal operating conditions, the voltage in the range of $U_{min2} \leq U \leq U_{min1}$ shall not cause any damage or failure, and shall permit continuing vehicle operation with some significant degradation. Rated vehicle power and performance will not be available, but reduced operation will be possible assuming onboard logic will automatically degrade the performance of the traction system (rolling stock) and auxiliaries. Typical abnormal operating conditions could include substation outage, loss of one or more transformers at the substation, utility supply problems, etc. See Section 20.7.4, Continuity of Power Supply in Case of Disturbances, for details.

- The setting of under-voltage relays in fixed installations or onboard rollin, g stock should be from 85 percent to 95 percent of U_{min2}.
- Both the following acceptance criteria for "Quality Index of Power Supply" for ac 2 X 25 kV autotransformer feed configuration shall be satisfied (refer to Section 8 of EN 50388:2005 – Railway Applications: Power Supply and Rolling Stock – Technical Criteria for the coordination between power supply (substations) and rolling stock to achieve interoperability):

U_m = > 22.5 kV

U_i => 19 kV (U_{min1} – Lowest permanent voltage

Where

Mean Useful Voltage (U_m) is the mean value of all rms voltages analyzed in the system simulation study, and gives an indication of the quality of the power supply for the entire system during the peak traffic period in the timetable, and

$U_m = \Sigma U_i/N$ where U_i is the rms ac voltage over the i^{th} second during the peak period for all trains in the system, and N is the total number of observations.

The TPS designer shall verify this by a traction power simulation study using the specific CHSTP design parameters.

20.6.3 Frequency

The nominal frequency of the supply voltage shall be 60 Hz.

Unless the requirements of the power supply utilities are more stringent, for systems with synchronous connection to an interconnected system, under normal operating conditions the mean value of the fundamental frequency measured over 10 seconds shall be within a range of:

60 Hz +/- 1% (i.e., 59.4 Hz … 60.6 Hz) for 99.5 percent of a year

60 Hz +4%/-6% (i.e., 56.4 Hz … 62.4 Hz) for 100 percent of the time

20.7 System Configuration

20.7.1 Verification of Configuration

The configuration of the TPS and distribution system shall be confirmed by a computer-based traction power load flow study.

20.7.2 Spacing of Traction Power Facilities

SS sites shall be located at approximately 30-mile intervals along the Authority's right-of-way.

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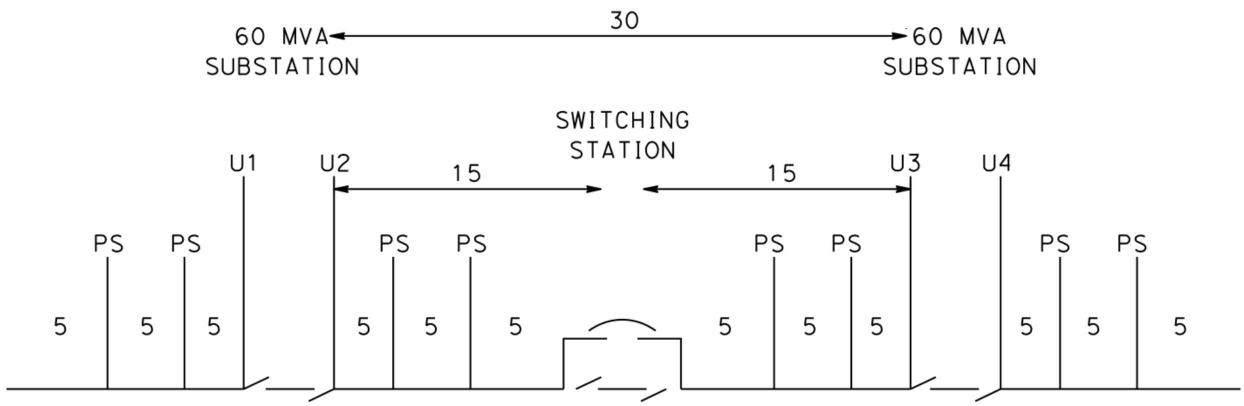
SWS sites shall be located approximately midway between adjacent SS sites.

PS sites should be located at approximately 5-mile intervals between switching station and substation sites.

Figure 20-1: Simplified Feeding Arrangement – 2x25 kV Autotransformer Feed System



At some locations because of site-specific alignment, geographical or other constraints, deviations from the criteria may be permitted where the guideline No. 3 is not practically achievable. Modified spacing of the TPF shall be proved and confirmed to the Authority's satisfaction by a computer-based traction power load-flow analysis.[4] The locations of the SS and the SWS shall not be changed.

With a view to preventing stalling of trains at the phase-breaks, the phase breaks of SS and SWS should not be located within a 4500 feet distance from the nearest end of any railway station, wayside crossover, or tunnel portal. The track grades at the phase breaks and to 4500 feet on either side shall not be greater than 0.6%. Any exception shall require the approval of the Authority.[5]

20.7.3 Additional Location Requirements

The following additional location requirements shall be met:

1. If the TPF is located in the proximity of or beneath HST tracks located on aerial trackways, it shall be ensured that that the main power transformers and AT and their outdoor switchgear are located in an open area (shall not be located underneath structures), and that proper clearances are available for the main gantry.

[4] This aspect of approval/concurrence by the Authority will be moved to another contract document. This aspect involves procurement of additional land for the changed location of the paralleling stations, and is not amenable to "self certification."

[5] This aspect of approval/concurrence by the Authority will be moved to another contract document. This aspect can be "self-certified."

2. Access shall be provided between the TPF and the HST track. If this cannot be provided, an alternate method of providing vehicular access to the trackside shall be provided for approval of the Authority.[6] Access to the track at TPF sites is required for service and maintenance vehicles access. See the *Civil* chapter for additional requirements.

3. There shall be a strain gantry located within the Authority's right-of-way parallel to and on the opposite side of the track away from the TPF, with footprints exactly equal to that of the main gantry.

4. If the TPF is located adjacent to the HST track, the main gantry shall be located within the TPF fence. If the TPF is located away from the track, the main gantry shall be located within the Authority's right-of-way, parallel to and towards the TPF side of the track. In this case, duct banks and manholes for laying power cables from the TPF to the main gantry shall be laid on the strip of land provided for this purpose.

5. At locations where track alignment is on aerial structures, the TPF shall be located on ground, and power cables shall be routed from the TPF to the gantries located on the aerial structures through duct banks and manholes and then onto the vertical columns of the aerial structures. See Section 20.9.3 [Foundations] and the *Structures* chapter for additional requirements.

6. At locations where track alignment is in trenches, the TPF shall be located on ground, and power cables shall be routed from the TPF to the motor operated disconnect switch (MOD) assemblies located adjacent to the trench alignment through duct banks and manholes and then onto the OCS. If the TPF is located adjacent to the trench alignment, the MODs will be located within the TPF fence. See Standard and Directive Drawings for further details.

7. Phase-breaks shall not be located in tunnels.

8. If an AT connection to the OCS must be located in a tunnel, the respective PS shall be located at or close to the entrance of the tunnel, and feeder cables shall be carried along the walls of the tunnel to provide connection to the OCS. See Standard and Directive Drawings for further details.

9. In all cases the traction gantries, 25 kV feeders, traction return cables, motor operated disconnect switches, wayside power control cubicles, manholes, ductbanks, and other traction power supply related equipment shall be located along the track alignment at-grade, on aerial structures, in trenches and in the tunnels (as applicable) conforming to the structure gauge, vehicle gauge and track clearance requirements. See *Trackway Clearances, Utilities, Structures*, and *Tunnels* chapters for additional requirements.

[6] This aspect of approval/concurrence by the Authority will be moved to another contract document. This aspect is amenable to "self-certification" provided no additional land is required.

20.7.4 Continuity of Power Supply in Case of Disturbances

The TPS and the OCS shall be designed to enable continuity of operation in case of disturbances such that:

- There must be no degradation of train performance in case of single electrical contingency conditions, that is isolation of any 1 main power transformer in a substation, 1 autotransformer in a PS/switching station or of NF for any one electrical section, and
- There must be no stranding of trains in case of double electrical contingency conditions (simultaneous occurrence of more than 1 single electrical contingency condition in any electrical section).
- The minimum permanent voltage at the train's pantograph (both under normal as well as single contingency conditions) is 19 kV.
- The acceptance criteria of Quality Index of Power described in Section 20.6.2.7 (in Voltage-Related Requirements) are satisfied.
- The minimum non-permanent voltage at the train's pantograph (under double electrical contingency conditions) is 17.5 kV.

Also see Section 20.6.2, Voltage-Related Requirements.

20.7.5 Electrical Protection Coordination

The protection system for the TES shall be designed for a maximum catenary – rails short-circuit fault current of 15 kA.

Compatibility of protective systems between traction unit (rolling stock) and SS shall be verified for the following:

- When any internal fault occurs within the traction units, the SS feeder circuit breaker and the traction unit circuit breaker may trip immediately. However, the traction unit circuit breaker should trip in order to avoid the substation circuit breaker tripping.
- After the substation circuit breakers have tripped, these breakers shall be capable of being reclosed either automatically or manually only after a lapse of at least 3 seconds.
- The traction unit circuit breakers shall trip automatically within 3 seconds after loss of line voltage.
- On re-energization, the traction unit circuit breaker shall not reclose within 3 seconds of the line being re-energized.

Refer to the *Rolling Stock-Core Systems Interfaces* chapter for additional requirements.

20.7.6 Protective Provisions of Traction Power Facilities

Additional information is found in the *Grounding and Bonding Requirements* chapter.

The TES design presupposes running rails electrically insulated from ground, but connected to ground at intervals, at least at TPF locations, through the neutral points of impedance bonds. A part of the return current will flow through the running rails because they are part of the traction return system. Because of the impedance of the rails, this return current flow will cause a voltage with respect to the ground especially at locations away from the ground connections.

Electrical safety of the TPS shall be achieved by the following means:

- The installations shall be designed and tested such that the permissible touch voltages caused by the traction system under fault conditions or in operating conditions shall not exceed values specified in the *Grounding and Bonding Requirements* chapter.
- A direct connection shall be made between the return circuit and the grounding system of the TPF (SS, SWS, and PS).
- Each TPF shall be connected to the running rails and the aerial ground wire by at least two return cables. Each return cable shall be of sufficient size to carry the maximum load current, thereby allowing for the failure of one return cable. The connection to the running rails is through impedance bonds.
- Fuses, non-lockable switches, and joint straps that can be released without a tool shall not be installed in the return circuit.

The rated impulse voltage (U_{Ni}) and the short-duration power-frequency (ac) test level voltage UA (kV rms) shall be as given in the Table 20-1. (Refer to European Standard EN 50124-1 - 2001: Railway Applications – Insulation Coordination – Part 1: Basic Requirements – Clearances and Creepage Distances for all Electrical and Electronic Equipment.)

Table 20-1: Rated Impulse Voltage and Power Frequency Test Voltage

	Rated Impulse Voltage U_{Ni} (kV_{crest})[a]	Short-Duration Power-Frequency (ac) Test Level Voltage U_A (kV rms)[b]
Between Catenary/Negative Feeder and Ground	200	95
Between Catenary and Negative Feeder	250	95

Notes:

[a] Based on Table A.2, EN 50124-1:2001 (against Rated Insulation Voltage 27.5 kV – Higher Values for Fixed Installations)

[b] Based on Table B.1, EN 50124-1:2001 (against U_{Ni} of 200 kV and 250 kV, respectively)

All TPF shall be fenced against unauthorized access. At locations where TPF are located adjacent to the Authority's right-of-way, a fence shall be installed for the complete length of the TPF site between the TPF and the trackside. See the *Civil* chapter for additional requirements.

The grounding of TPF shall be integrated into the general grounding system along the route to comply with the requirements for mitigating electric shock as specified above.

20.7.7 Harmonic Distortion Limits

The harmonic distortion limits for individual and total harmonic distortion of voltage and current shall be followed per of IEEE Std 519, "IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems," unless the limits imposed by the concerned power supply utility are more strict.

20.7.8 Electromagnetic Compatibility

The TPS installations shall conform to the criteria in Traction Electrification System EMC Design Criteria of the *Electromagnetic Compatibility and Interference* chapter.

20.8 Traction Electrification System Interfaces

See other Contract Documents for systems interface details.

20.9 Traction Power Facilities and Associated Sites

20.9.1 General Site Requirements

Access/Egress – Access to each TPF site shall be required both during construction and for operation and maintenance purposes. Access roads leading to/from the TPF shall be designed in accordance with the ordinances of the local jurisdiction, in which the TPF are located. Refer to the *Civil* chapter for additional requirements.

Access roads and gates at TPF shall be sized to permit placement and removal of all TPF equipment; and access by first responders/fire department vehicles.

The design of the access roadways and equipment arrangement within the TPF shall ensure that equipment owned by and/or maintained by the local power utility company is located within a distance from the access roadway, as specified by the relevant power supply utility.

Every TPF will have a communications enclosure for locating communications interface equipment relating to TES SCADA and other associated equipment. Separate access shall be provided for the communications staff to the communications enclosure located in the TPF.

Security – The design of the TPF sites shall include a barrier (e.g., fence, CMU block wall), whose height above finished grade shall comply with the requirements specified in the *Civil* chapter, along the complete perimeter to prevent unauthorized access.

The design of the access gates shall include a means to secure the gates and prevent unauthorized access.

All equipment enclosures shall have an Authority-approved locking device. See TBD for additional details.[7]

The doorways at the prefabricated equipment enclosures shall include Authority-approved intrusion detection hardware, which shall be remotely monitored. See TBD for additional details.[8]

Parking Spaces – A minimum of 4 parking spaces for operations and maintenance (O&M) personnel shall be incorporated into the design of each TPF site.

Each parking space shall be at least 18 feet (length) by 9 feet (width).

Refer to the *Civil* chapter for additional requirements.

Aesthetic Treatments – TPF and their sites shall be designed to minimize the adverse visual impact on the areas in which they are located and to be in compliance with the appropriate architectural and environmental guidelines. See TBD for requirements.[9]

Drainage – See the *Drainage* chapter for the requirements.

Equipment/Enclosure Safety Signage – Safety signage shall be provided at all TPF in accordance with applicable codes and standards (e.g. Cal/OSHA, NEC, NESC, CPUC GOs, etc.). See the *Civil* chapter for additional requirements.

Protective Barriers – Protective barriers shall be provided at traction installations that are subject to road vehicle damage. See the *Civil* chapter.

20.9.2 Equipment Support Steel

Equipment support steel (steel members for supporting TPS equipment) shall be designed to be assembled on site using bolted connections.

Equipment support steel shall have a hot-dipped galvanized finish, suitable for the intended working environment.

Structural steel shall include a cleat/bracket with 2 holes to permit 2-hole grounding/bonding lug connections.

See the *Structures* chapter for additional requirements.

[7] This information is not available at present.
[8] This information is not available at present.
[9] This information is not available at present.

20.9.3 Foundations

The design of the foundations for all of the equipment and structural steel located at the TPF and wayside power control cubicles (WPC) shall:

- Conform to established civil and structural engineering practices: California Building Code, ASTM, ACI, AISC, NESC, and other applicable codes and standards.
- Be structurally capable of withstanding the live loads and dead loads occurring during installation, operation, and maintenance.
- Consider, amongst other issues, the local flood, soil, and seismic conditions at each TPF and WPC site. Refer to the *Drainage* chapter for establishing the floor height above the 100-year and 500-year flood elevations. Refer to the *Seismic* and *Structures* chapters for specific requirements.

The design of the foundations shall ensure water drains to the site drainage system and prevents standing water at/under equipment and/or structural steel.

Anchor bolts (hold-down bolts) shall be galvanized.

See the *Structures* chapter for additional requirements.

The foundations of each prefabricated enclosure for 25-kV indoor switchgear shall include the following features:

- A concrete slab, extending 6 inches beyond the outside walls of the enclosure (excluding doorways, which shall be provided with landing pad).
- Subject to the height between the finished grade and the enclosure floor, a concrete staircase at doorways used for personnel access/egress designed in accordance with federal, state, and/or local codes.
- A ramp at doorways used for equipment placement and removal (in addition to personnel access/egress), designed in accordance with federal, state and/or local codes.
- The interface of the indoor switchgear room with the 25 kV cable ducts shall be via cable trench with removable covers. If the connections between power cables and circuit breakers are not near the edge of the foundation, a cable vault underneath the switchgear enclosure shall be provided, as part of the foundation structure. Access to the cable vault shall be via bulkhead entrance/exterior doorway, which shall be large enough (of adequate width, depth and height) to provide convenient working space to maintenance personnel for installation and maintenance of medium voltage cables, terminations, surge arrestors and other equipment required by the system design. (See Sections 20.9.4 [High-Voltage Transformers] to 20.9.9 [Transformer Oil Containment] for additional requirements.)

The design of the foundations associated with the HV transformers and AT shall prevent oil from entering the site drainage system and shall contain fluids in accordance with federal, state, and local codes.

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See the *Seismic* and *Structures* chapters for additional requirements.

20.9.4 High-Voltage Transformers

HV transformers shall be outdoor type, mineral-oil-insulated, and self-cooled, with a 60 MVA ONAN nominal rating. The transformers shall be furnished and installed without cooling fans. However, transformer design shall incorporate provisions for possible installation of cooling fans in the future.

The HV transformers shall conform to the appropriate duty class as specified in the European Standard EN 50329:2003+A1:2010, corresponding to the load curves based on the traction power load flow study.

The HV transformers shall be single-phase, with the primary winding connected between 2 phases of the incoming 115kV (or 230kV) line of the local utility company. The secondary winding may be constructed as either 1 winding with its center point brought out and grounded, or it may comprise 2 separate windings such that the voltages in them are in counter-phase (180 degrees apart). The no-load voltage on the secondary side, assuming nominal 115 kV/230 kV on the primary and a neutral tap, shall be 52.5/26.25 kV. Transformer impedance shall be around 10 percent on a 60 MVA basis.

For TPF with more than 1 transformer, sufficient space or masonry fire barriers between the transformers shall be provided to preclude a transformer fire from damaging other transformers.

The design of the transformers shall be such as to minimize the generation of acoustic noise and the noise levels produced shall not exceed the requirements as specified in the *General* chapter. See IEEE Standard C.57.12.00 and NEMA Standard TR1 for additional requirements.

Each HV transformer shall be equipped with no-load tap changer on the primary side, and automatic on-load tap changer on the secondary side.

20.9.5 Autotransformers

AT shall be outdoor type, mineral-oil-insulated, and self-cooled, with a 20 MVA ONAN nominal rating.

The AT shall conform to the appropriate duty class as specified in the European Standard EN 50329:2003+A1:2010, corresponding to the load curves based on the traction power load flow study.

The AT shall be single-phase, with the primary winding connected between the catenary and NF circuits, and the center tap grounded and connected to the running rails (and to the static wires). The nominal voltage of the primary winding shall be 50.0 kV between the winding terminals, and 25.0 kV to ground. Turns ratio between OCS side and center tap to center tap

and NF side shall be 1:1. Autotransformer design shall minimize leakage reactance, and the autotransformer impedance shall be around 1.2 percent.

20.9.6 High-Voltage Switchgear

Each HV transformer shall be connected to the incoming utility line via outdoor HV switchgear of the same voltage class as the utility supply line (nominal 115 kV or 230 kV). The switchgear shall include a circuit breaker, motorized gang-operated air isolation switches, instrument transformers and other accessories. The basic impulse level rating of the outdoor HV switchgear shall be 550 kV for 115 kV line and 900 kV for 230 kV line.

The power circuit breaker shall be outdoor type, 121 kV rms maximum operating voltage for 115 kV line (or 242 kV for 230 kV line), 550 kV (or 900 kV) basic impulse level, double-pole, SF6 insulated, free standing. Short-circuit interrupting current capability shall be 40 kA. The circuit breaker shall be rated for operation on a nominal 115 kV (or 230 kV), effectively grounded utility transmission system. It shall be similar to a 3-phase circuit breaker of the same voltage rating, except that one phase/pole will not be used.

20.9.7 Prefabricated Enclosures for 25 kV Indoor Switchgear

The 25 kV phase-to-ground class switchgear and associated control and protection systems of the SS, SWS, and PS shall be indoor type. The medium-voltage switchgear and related protection control, and auxiliary systems at each TPF site shall be housed in a prefabricated walk-in, climatized, and transportable metal enclosure (or in 2 separate enclosures). The enclosure shall be fabricated from sheet steel, mounted on structural steel base, and provided with internal and external high durability paint finishes designed to prevent corrosion over the life of the enclosures. Non-painted steel surfaces shall be hot-dipped galvanized after fabrication. Damage to galvanized areas caused by the fabrication process shall be repaired in accordance with ASTM A780/A780M: Standard Practice for Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings.

At least 2 doorways, located at diametrically opposite ends of the enclosures, shall be provided to permit an unobstructed means of egress in accordance with the California Building Code.

One of the doorways shall be sized and located to allow removal or replacement of the largest piece of equipment in the room and shall be located such that the equipment can be moved through the enclosure to the outside for transporting off-site.

The design of the enclosures shall ensure a dry internal environment within the specified temperature and humidity limits.

The enclosures shall be designed to withstand the level of structural, wind, and seismic loading as specified in the *General, Seismic* and *Structures* chapters.

The floor and walls of each enclosure shall be designed to support the equipment, raceway, and cable tray systems installed and to provide openings to cable trenches, without buckling, bending, or sagging.

20.9.8 25 kV Single-Phase Switchgear

The design of the 25 kV, single-phase, 60 Hz, ac switchgear shall include at a minimum the following features:

- The 25 kV class single-phase circuit breakers shall be designed per applicable European standards for railway applications, shall be suitable for indoor installation, and shall have rated maximum operating voltage to ground 29 kV. Circuit breakers protecting catenary or NF circuits shall be single pole. Circuit breakers for the AT or on the secondary side of the HV transformers shall be double-pole. Nominal phase-to-ground voltage for both single-pole and double-pole circuit breakers will be 25 kV in all the TPF. The pole-to-pole nominal voltages for the double-pole circuit breakers shall be twice the respective voltages to ground.
- The circuit breakers shall be either of the sealed vacuum or SF6 type. If SF6 circuit breakers are proposed, an evaluation shall be provided to indicate that such medium-voltage indoor switchgear does not conflict with state or local regulations concerning the SF6 gas and its byproducts from arc extinguishing as hazardous materials.
- The ac switchgear shall be either metal-clad or metal enclosed, and of the same voltage rating as the circuit breakers. If metal-enclosed, then disconnect switches shall be provided between the circuit breakers and the common bus to allow the isolation of any circuit breaker for maintenance or repairs. In case of metal-clad switchgear with draw-out circuit breakers, the stationary contacts of the circuit breakers can be connected directly to the common bus without a disconnect switch. The basic impulse level of the switchgear shall be 200 kV or higher.
- Power connections from the catenary and NF of each track to the 25-kV buses of SS, SWS, and PS shall be through single-phase circuit breakers (forming part of the indoor switchgear lineups) and outdoor gantry-mounted disconnect switches. The latter shall be motorized and connected in series with the circuit breakers, to provide visible circuit isolation means between tracks and TPF. As noted, if metal-enclosed switchgear is used, an additional set of in-series disconnect switches shall be provided between the ac circuit breakers and the common bus. The disconnects in series with the circuit breakers shall be no-load type and shall be interlocked with the respective circuit breaker so that the switch cannot be operated unless the circuit breaker is open.
- Switchgear in the TPF and outdoor-mounted disconnect switches shall be appropriately interlocked with the associated circuit breakers to ensure the safety of O&M personnel and equipment for all possible circuit configurations, and to avoid inadvertent paralleling of different electrical sections (which will be supplied by out-of-phase voltage systems).

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- Circuit breakers equipped with protective relaying for catenary and NF circuit protection shall feature multi-stage auto-reclosing capability..
- Equipment interconnecting buses shall be copper. Buses shall be sized to limit temperature rise in accordance with the applicable codes and standards. Buses shall be adequately supported to withstand the forces from short-circuit currents matching the ratings of the circuit breakers.
- If draw-out circuit breakers are selected, the design of the switchgear shall include automatic shutters to protect personnel from accidental contact with live power circuits when the truck-mounted circuit breaker is removed from the cubicle.
- The design of the circuit breaker shall include means for physical (padlocking) lockout/tag-out when the circuit breaker is in the disconnected position.
- Visual indication of the status of the circuit breaker (i.e., closed or open) shall be displayed on the front door of the circuit breaker cubicle by indicator lights and by mechanical flag indicators.
- All circuit breakers and motorized disconnect switches shall be locally and remotely controlled. Control means to operate all switchgear remotely from the Operations Control Center (OCC) or the Regional Control Center (RCC), and locally via a mimic annunciation panel, graphical user interface, and/or control switches on the equipment shall be provided.
- A mimic annunciation panel shall be provided at each TPF that permits O&M personnel to monitor and control circuit breakers and/or disconnect switches located at the traction power facility and its vicinity. The design of the mimic annunciation panel shall include a sectionalization plan on the exterior of the panel, complete with control switches and status indication lights located adjacent to the control switches (of the respective circuit breakers and disconnection switches).
- Equipment space heaters, which are thermostatically and humid-statically controlled, shall be provided in the ac switchgear cubicles and control equipment cabinets.
- Feeder cable terminations shall be designed to prevent accidental contact and alleviate voltage stress zones. If no-load break elbows are available for this voltage class from suppliers of elbow style terminations, the cable terminations shall be via elbows.

See Section 20.9.15, Relay Protection, for circuit breaker protection requirements.

20.9.9 Transformer Oil Containment

Transformer oil containment system shall have open area covered with non-skid galvanized steel grating on all sides of the transformer concrete pad as shown in the Standard and Directive Drawings and shall conform to IEEE-980 and other applicable codes/standards/guidelines including 40 CFR, Part 112 – Oil Pollution Prevention Regulations – published by the Environmental Protection Agency. See the *Grounding and Bonding Requirements* chapter for grounding of steel grating.

Typically, at one corner of this structure, a sump shall be provided. All 4 sides shall slope 1 percent minimum towards the sump.

Interior surface of the containment basin shall be painted with epoxy primer and polyurethane finish coat.

Waterstops shall be provided at the construction joints.

Structural steel beams shall support the galvanized steel grating.

System for reclamation and/or disposal of spilled oil shall be designed that shall conform to the applicable codes, standards and regulations.

Active fire suppression system shall be designed by the TPS Designer.

20.9.10 Utility Interface Equipment: Ancillary Equipment Mandated by PG&E, SCE, LADWP, City of Anaheim, etc. to Protect Their 115 kV (or 230 kV) Transmission Network

Refer to the general requirements specified by the relevant power supply utilities. Site-specific requirements have been indicated elsewhere in the Contract Documents.[10]

20.9.11 Resistor Banks

Requirements have been specified elsewhere in the Contract Documents.[11]

20.9.12 Painting and Finishes

All electrical equipment enclosures, materials, and appurtenances shall have a corrosion resistant finish and shall be suitable for use in the environment in which they are installed.

20.9.13 Auxiliary and Control Power

Auxiliary power, for lighting, receptacles and so forth, at prefabricated equipment enclosures, can be derived from the following:

- Two local power utility services, or
- Locally by tapping of each 25 kV bus and transforming through auxiliary transformers, to the utilization voltage, or
- One local power utility service and one tapping of the 25 kV bus (which is transformed to the utilization voltage).

[10] This information has still to be collected.

[11] This information has still to be finalized. It depends on whether regenerated energy will be fed back into the HV grid network.

The primary auxiliary power source shall be switched to the secondary auxiliary power via an automatic transfer switch.

The auxiliary transformer shall be sized based upon the demand electrical load. Auxiliary transformers may be indoor or outdoor with suitable enclosures according to their location

See Section 20.14.2, Auxiliary Power Services, for additional requirements.

Control power at TPF shall be 125 V dc and originate from a battery and battery charger.

See Section 20.11.2, Emergency Power Requirements, for additional requirements for control power.

20.9.14 Lighting

Exterior lighting layouts shall relate to the equipment locations and access/egress routes of both pedestrians and road vehicles.[12]

Exterior lighting shall be activated manually by photo cell or astronomical clock controls.

Exterior lighting shall provide at least a uniform lighting level of 10 foot-candles within the barriered area of the TPF sites and 5 foot-candles within the 10-foot perimeter outside each site's barrier.

Interior lighting levels at each prefabricated equipment enclosure shall be at least 20 foot-candles.

Emergency lighting shall be provided at each prefabricated equipment enclosure, which is capable of illuminating exit paths with at least 1 foot-candle.

20.9.15 Relay Protection

The design of the relay protection system shall:

- Protect the TES equipment and cables within the TPF and the catenary and NF against short-circuit faults, overloading, and subcomponent failures.
- Include fault location and discrimination capabilities, including automatic circuit breaker reclosing for catenary and NF circuits, as well as manual local and remote re-closure management.
- Provide proper coordination and selectivity for rapid fault clearance to the affected area of the system only, preventing as much as possible the loss of power to the healthy sections of the TES.

[12] There seems to be confusion about the Authority's view on exterior lighting—whether to be provided and where to be provided. This is a place-holder for the time being.

- Adequately discriminate between short-term high loads and fault conditions.

HV relay protection equipment on the primary side of the traction power substations shall be coordinated with the respective utility company as applicable.

Each HV transformer and autotransformer shall be provided with protective devices, including but not limited to the following:

- Overcurrent relays on the primary side (HV transformers only)
- Differential relays
- Ground overcurrent relay on the secondary side
- Over-temperature protection
- Oil-level and oil-pressure detection relays and alarms

Catenary and NF circuit breakers shall be provided with electronic, microprocessor-based protective relays and devices to protect against short-circuits and conductor overloading conditions. The number and type of protective devices for a particular circuit breaker shall be based on the overall relay protection scheme for the TES. Typically, the protective relays for catenary and NF circuits employed shall include, but not be limited to, the following:

- Instantaneous and time delay overcurrent relays (for backup short-circuit protection).
- Multi-zone distance relays (for primary short-circuit protection). The distance relays shall feature at least 3 zones with separately adjustable parameters.
- Undervoltage/overvoltage relay.
- Thermal overload relay, for protection of the downstream catenary or NF circuit against overheating. This relay shall be thermal replica type and shall include an ambient temperature probe located outside the traction power facility, with a feedback loop to the relay.
- Phase directional overcurrent relay.
- Multi-shot automatic reclosing relay (maximum number of auto-reclosing attempts and pause durations to be determined in coordination with the overall protective relaying scheme).

The design of the relay protection scheme shall be presented to the Authority for approval.[13]

[13] This aspect of approval/concurrence by the Authority will be moved to another contract document. This can be "self-certified."

20.9.16 Protective Relaying Scheme for Catenary and NF Fault Detection

Circuit breakers equipped with distance relays shall feature multi-stage auto-reclosing capability, and catenary and NF circuit breakers shall have separate protective relaying. The preferred relay protection scheme shall be based on the following general principles:

- The distance relays shall be located in the SS, and possibly also in the SWS (for use during contingency operations with one SS completely out-of-service). The distance relays shall be set to protect the entire feed section from the SS to the SWS, or to the end-of-line (in case of the first and last electrical sections). Upon fault detection by one of the distance relays, initially both tracks shall be tripped. During the pause before the first auto-reclosing, the circuit breakers that tie electrically the 2 tracks at the PS and SWS in the affected feed section shall open, isolating electrically the 2 tracks. Opening of these circuit breakers shall be by local undervoltage relays.
- Upon reclosing of the circuit breakers in the SS, if the fault has been transient, both tracks will remain energized. In such case, following time delay (presence of voltage indicating power has been restored), all circuit breakers in the PS and SWS shall reclose, restoring the TES to its normal configuration. If the fault is still present, then power will be restored to the healthy track only, as the breaker feeding the fault will be tripped again.
- Auto-reclosing on the faulted track shall be attempted several times, and if the circuit breaker is tripped at the last attempt, the conclusion will be that the fault is permanent. The next stage consists of approximately locating the fault between a pair of track interlockings (or between an SS and its adjoining SWS, or between a track interlocking and the adjacent TPF [SS or SWS], depending on the location of the fault and the TES configuration), and isolating the faulted subsection by opening (the N.C.) disconnect switches at the interlockings (or SS and the adjoining SWS, or the interlocking and the TPF) bracketing the fault, and then restoring power to the healthy segments of the affected track. The procedure for fault isolation (i.e., limiting the power loss between adjacent interlockings on one track) can be either manual—conducted by operators in the OCC/RCC using remote control of circuit breakers and motorized switches—or it can be automated (driven by PLC-based logic). Both alternatives shall be investigated and presented to the Authority for a decision.[14]

The protective relaying scheme outlined above shall be analyzed for both normal and contingency configurations of the TES. The contingency configurations shall include, at a minimum, the following:

- Operational loss of one HV transformer of any substation (with the second transformer supplying both feed sections of the affected substation)
- Loss of a PS

[14] This aspect of approval/concurrence by the Authority will be moved to another contract document. This aspect is NOT amenable to “self certification.”

- Loss of one catenary or NF circuit breaker in an SS, SWS or a PS
- Complete loss of an SS, with the adjacent healthy SS providing feed to the extended feed sections.
- Design a detailed protection scheme based on the above principles. Suggest any alternative relay protection scheme bringing out its benefits. The Authority will decide on the scheme to be implemented.[15]

20.9.17 Fire and Life Safety

A fire alarm control system shall be installed at each prefabricated 25 kV switchgear room in accordance with NFPA 72 and CFR Title 19.

Fire alarm devices, initiating devices, notification appliances and signaling line circuits shall be designated as Class A, as defined in NFPA 72.

The fire alarm system shall be electrically supervised and shall be furnished with emergency backup power.

A portable emergency eye-wash unit shall be provided at a location adjacent to the station battery.

A portable fire extinguisher, sized per federal, state, and local code requirements shall be provided in each prefabricated 25 kV switchgear room.

Refer to the *Systems Safety and Security Plans*[16] chapter for additional requirements. Conform to all applicable local codes and regulations.

20.9.18 Test Cabinets

If withdrawable circuit breakers (metal-clad switchgear) are selected, a test cabinet shall be provided at each prefabricated 25 kV switchgear room for the testing of the truck-mounted 25 kV circuit breakers.

20.9.19 Communications

See the *Communications* chapter for these requirements.

20.9.20 SCADA Equipment

See the TES SCADA System related sections in the *Supervisory Control and Data Acquisition Subsystems* chapter for these requirements.

[15] This aspect of approval/concurrence by the Authority will be moved to another contract document. This aspect is NOT amenable to "self certification."

[16] To confirm that the "Safety and Security Plans" are included in the contract documents.

20.9.21 Metering Equipment

- Pacific Gas and Electric, Southern California Electric, Los Angeles Department of Water and Power, City of Anaheim, etc.
  - Conform to the requirements of the relevant power supply utilities. Refer to other Contract Documents for additional requirements.[17]
- CHSTP
  - See *Supervisory Control and Data Acquisition Subsystems* chapter for these requirements.

Metering instrumentation shall be provided on the primary side of the HV transformers, AT, and on each individual catenary and NF circuit.

20.9.22 Grounding, Bonding and Lightning Protection

See *Grounding and Bonding Requirements* chapter for details.

20.9.23 Real Estate Requirements: Approximate Footprints for the TPF

(Also refer to Sections 20.4.6 [High-Voltage Utility Connections] and 20.7.3 [Additional Location Requirements].)

The size of the TPF sites has been determined considering the following requirements:

- Site shall accommodate all of the equipment necessary for the level of service, associated roadway, and right-of-way requirements.
- Design requirements imposed by utility companies and/or the local jurisdictional entities.
- Space provisions for future equipment (normally 20 percent), as approved by the Authority.[18]
- Space requirements for the placement and removal of equipment.

Where practical, the footprints of different TPF (considering the above requirements), shall be limited to as follows:

- SS (2 power transformers, each of 60 MVA capacity) with 2 HV utility supply circuits – 200 feet x 160 feet
- SS (3 power transformers, each of 60 MVA capacity) with 2 HV utility supply circuits – 200 feet x 210 feet
- SWS with 2, 20 MVA, 2 x 25kV AT – 160 feet x 90 feet

[17] This information is still not available.

[18] This requirement may be common to many subsystems, and may be shifted to another contract document with a reference at this location.

- PS with 1, 20 MVA, 2 x 25kV AT – 120 feet x 80 feet

These are typical footprints of different TPF. Orientation of the TPF with respect to tracks, locations of utility supply circuits, equipment, and road access shall be determined on a site-by-site basis.

In general, all SS shall be configured with 2 power transformers where practical. Some locations shall require an SS configuration with 3 power transformers. See Standard and Directive Drawings in this connection.

Provision has also been kept for locating a power utility switching station close to each SS. Typically the utility's switching station will have a footprint of 220 feet x 160 feet. This utility switching station has been, to the extent practical, located adjacent to the SS. If the utility's switching station is located away from the SS, easements shall be provided for installing the HV line connection from the utility's switching station to the SS.

The design and installation of the TPF, power utility switching stations and the HV line connections shall conform to the requirements of all applicable codes / standards / guidelines and the structure gauge, vehicle gauge and track clearance requirements.

TPF Sites – The TPS detailed design, including interconnections to the OCS/power utility network, shall be carried out within the limits of the land plots and easements earmarked for this purpose. If some additions/alterations are required to be made to these identified land plots/easements because of the results of the traction load flow studies/calculations conducted by the Contractor and/or because of additional requirements of the power supply utilities, justifying data for the additional requirements shall be provided to the satisfaction of the Authority.[19]

20.10 Electrical Materials

20.10.1 Equipment Identification

All equipment shall be uniquely identified in accordance with the Authority's requirements to indicate geographical location, function, feeding point (if applicable), and ownership.

The equipment identifiers shall be permanent and located on the front and rear (where rear access is provided) of each equipment enclosure.

Refer to the Contract Documents for the Authority-approved identification and nomenclature system.

[19] This aspect of approval/concurrence by the Authority will be moved to another contract document. This is NOT a case of "self-certification" because it involves acquisition of additional land plots.

20.10.2 Equipment Enclosures

Equipment enclosures shall be of NEMA classification suitable for the environment in which the equipment is operating.

20.10.3 Raceway

Exposed conduits shall be rigid galvanized steel and shall be minimum 3/4-inch trade size.

All raceways shall be installed parallel or perpendicular to the building members of the TPF.

The number of bends in any 1 conduit run shall not exceed the limit specified in the CEC and NEC.

The bend radius of exposed and/or underground raceway systems shall be sufficient to maintain the cable side pressures within manufacturer's recommendations during cable pulling activities and shall conform to applicable codes/standards.

All exposed raceways shall be supported/secured to the walls and/or ceiling of the prefabricated 25 kV switchgear, and Control and Relay Room equipment enclosures in accordance with standard industry practice and the CEC and NEC.

Emergency circuits (e.g., fire detection, emergency power) shall not share the same raceway or enclosures with other systems.

Embedded conduits shall be minimum 1-inch trade size. See the *Utilities* chapter for conduits crossing under the trackbed.

All underground raceways shall utilize PVC schedule 40, reinforced thermosetting resin conduit or similar conduits, be encased in steel-reinforced concrete (with red pigment) and comply to the requirements of the CEC, NEC, NESC, CPUC General Order 128, and applicable codes and standards. See the *Structures* chapter for additional requirements with regard to ductbanks.

Underground raceways shall slope away from the TPF and towards manholes, pullboxes, etc., at a minimum rate of 3 inches per 100 feet. Raceway entrances in manholes, pullboxes, etc. shall be sealed against entry of silt, debris, rodents, etc. into raceways.

Tracer/detectable tape shall be installed in accordance with Standard Specifications Section 33 05 28: Trenching and Backfilling for Utilities.

HV, LV and communications raceway sharing the same ductbank shall not be routed through the same manholes, pullboxes, etc., and shall be physically separated per applicable codes for the entire length of the ductbank.

Ductbanks shall run as directly as practicable and shall be located to avoid interference with civil structures and sub-grade utilities.

All ductbanks shall be designed and laid conforming to all the applicable codes / standards / guidelines. See *Utilities* and *Facility Power and Lighting System* chapters for additional requirements.

20.10.4 Cable Tray Systems

Cable tray systems shall comply with NEMA VE 1.

Cable tray systems shall be engineered to comply with the following requirements:

- The cable tray system shall be fully enclosed metal cable trays hot-dipped galvanized after fabrication, with full system appendages.
- The drop-offs to all different points of utilization shall be conduit. Bushed conduit should be used wherever possible.
- The cable tray system construction shall be secure and prevent inadvertent access by unauthorized parties.
- The cable tray system shall have suitable strength and rigidity to provide adequate support for all the contained cables.
- The cable tray system shall include a means to ventilate the enclosed cables, so the heat generated by the cables can be safely dissipated.
- The cable tray system shall include barriers to segregate cables of different systems and voltage ratings.
- The cable tray system shall provide adequate cross-sectional area to permit neat alignment of the cables and avoid crossing or twisting.
- See also the *Facility Power and Lighting Systems* chapter for additional requirements.

20.10.5 Electrical Manholes and Pullboxes

All manholes and pull-boxes shall be designed and laid conforming to all the applicable codes / standards / guidelines. See *Utilities* and *Facility Power and Lighting System* chapters for additional requirements.

20.10.6 Cable Trenches for Power Cables

The interface of the 25 kV ductbanks with the prefabricated 25 kV switchgear houses shall be through cable trenches. Cable trenches shall be equipped with sump area for drainage by gravity or application of portable or fixed pumps as required

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Cable trenches shall be sized to accommodate the number and size of 25-kV circuits, with "positive/catenary" and "negative" cables separated by solid barrier, or installed on the opposite sides of the same trench (design to be approved by the Authority).[20]

At the foundation of the 25 kV switchgear house, the cable trenches shall transition into a cable vault of dimensions depending on the locations of the cable terminations at the switchgear. The cable vault shall have sufficient depth and height to provide for ease of installation and maintenance of the cable terminations and other equipment, such as surge arresters. A staircase, external to the prefabricated 25 kV switchgear equipment enclosures, shall be provided to permit access to the cable vault.

The design of the cable trenches shall include removable covers, extending a suitable distance from the edge of the switchgear house.

If SF6 switchgear is used, specific requirements for the design of the trenches directly below the switchgear shall be developed. Provide for all such requirements per existing law/codes/standards/regulations, in the TPS design.

20.10.7 Conductors

20.10.7.1 General

All electrical conductors shall be copper. Conductors and cables interconnecting equipment and/or cabinets shall be enclosed in raceways or cable tray systems.

Insulated traction power cables shall be single-conductor, with concentric neutral, shielded, and with external non-metallic jacket that is low smoke and sunlight resistant. The cables shall be suitable for installation in wet or dry locations, in underground conduit or exposed to the weather. The cables shall be rated for 30 kV phase-to-ground, and have 133 percent insulation level. See NFPA 130 for requirements of conductors when routed through tunnels, and see MIL standard 246431 series.

The cables shall be rated for 90°C continuous conductor temperature; 130°C for emergency short-term operation; and 250°C for short circuit conditions. The conductors shall be copper, with Class C stranding. The shield and concentric neutral shall be grounded at one end only, at the station ground bus, to avoid circulating ground return currents through the shield and neutral wires.

Traction power cables, connecting the 25 kV ac feeder breakers to the catenary and negative along-track feeders, and the running rails to the return bus, shall be sized to carry the maximum rms load currents, with due consideration for the installation environment. Cables shall be de-rated for installations in common underground duct banks or cable trays.

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[20] This aspect of approval/concurrence by the Authority will be moved to another contract document. It can be "self-certified."

Positive and negative 25kV feeders and neutral return feeders shall be standardized in multiples of a single copper conductor size to achieve the required circuit ampacity, especially if using only one cable requires sizes larger than 500 kcmil. The cables shall have sufficient ampacity to carry the maximum rms current imposed by the worst-case operating scenario on a continuous basis, without exceeding the 90°C conductor temperature limit.

Low voltage ac and dc power and control cables shall be copper conductors, rated for 600 V ac, with maximum conductor temperature of 90°C, and shall be suitable for installation in conduits, ducts, cable troughs, and cable trays. Cables exposed to the outdoor environment shall have a weather resistant jacket.

Instrumentation cable shall be 600 V insulated, multiple shielded, certified for installation in conduits, ducts, cable troughs, and cable trays. For multi-pair twisted cable, each pair shall be individually shielded and the cable shall have an overall shield insulated from the individual pair shields.

No cable splices shall be permitted.

20.10.7.2 Segregation

Insulated cables of different voltage classes shall not occupy the same conduit, cable tray, pull box, or manhole.

An underground ductbank may contain conduits for LV power and control cables, as well as HV traction power cables. However, separate pullboxes shall be provided for each type of cables.

For increased flexibility and system reliability during maintenance, 25 kV positive feeder conductors, 25 kV negative feeder conductors, and rail return feeder conductors shall not be routed through the same manholes and pullboxes. At TPF, if cables for the positive, negative, and/or neutral circuit need to share an overall common enclosure (such as cable trench), partitions or barriers shall be provided to achieve circuit separation.

20.10.7.3 Sizes of Low Voltage Power and Control Cables

LV power and control cables shall be sized on the basis of the maximum expected load current and acceptable voltage drop. In addition, conductor size shall not be less than the prescribed minimum, for mechanical integrity purposes.

Minimum size of LV power conductors shall be No. 12 AWG.

Minimum size of LV control conductors shall be No. 14 AWG.

Minimum size of analog indication cables shall be No. 16 AWG.

20.10.7.4 Color Coding

Refer to the *Facilities Power and Lighting Systems* chapter for requirement of color coding of all LV conductors. The color coding of HV and medium-voltage TPS conductors is specified in other Contract Documents.[21]

20.10.8 Wiring Devices

All light switches shall be 20 ampere grade.

All receptacles shall be 20 ampere grade, duplex, grounded type and have ground-fault circuit-interrupter protection for O&M personnel.

Receptacles shall be provided in accordance with the CEC and NEC at each prefabricated equipment enclosure.

Receptacles shall not be on lighting circuits.

See the *Facility Power and Lighting System* chapter for further details.

20.10.9 Light Fixtures

The voltage rating of fluorescent and high intensity discharge type lighting fixtures shall be 277 V ac. The voltage rating of incandescent fixtures or compact fluorescent fixtures shall be 120 V ac or 277 V ac. See the *Facility Power and Lighting Systems* chapter for further details.

20.11 Emergency Power

20.11.1 Emergency Electrical Loads

Emergency electrical loads are those ac and dc electrical loads required to be in operation during a disruption in the normal power supply to a TPF. These electrical loads include, but are not limited to, the following:

- Fire Alarm Control System
- Supervisory Control and Data Acquisition System
- Intrusion Detection System
- Control Power
- Emergency Lighting System
- See the *Facility Power and Lighting Systems* chapter for additional requirements.

[21] This is yet to be done.

20.11.2 Emergency Power Requirements

An emergency power source (i.e., battery and charger system), rated for at least 8 hours connected electrical load, shall be provided for all emergency lighting, exit signs, and other vital equipment located at TPF. In addition to the noted electrical loads, the emergency power source shall be able to support at least three operating cycles (where trip and close operation constitute one cycle) of all circuit breakers simultaneously.

The design of the batteries shall be NiCAD or VRLA or approved equivalent and, contain a life expectancy of at least 20 years and be low maintenance.

Transfer from the normal LV power source to the emergency power source shall be automatic.

The design of each TPF shall include a receptacle and associated switching equipment to permit the connection of a portable diesel generator during abnormal operating conditions.

20.12 Wayside Equipment

20.12.1 Wayside Power Control Cubicles

In addition to these TPF, Wayside Power Control Cubicles (WPC) will be located at railway stations including the universal crossovers at both ends, and on the wayside at universal crossovers, at tunnel portals, at rolling stock maintenance facilities, at wayside infrastructure maintenance facilities, and in tunnels longer than 3 miles. WPC is an enclosure for power supply equipment for operation of motorized disconnect switches and the associated SCADA equipment located at the wayside. Every WPC shall have, in general, a footprint of 10 feet x 8 feet. See Automatic Train Control (ATC) Standard and Directive Drawings (TBD)[22] for requirements of WPC at railway stations and at wayside universal crossovers. WPC at railway stations and wayside universal crossovers will be located in close vicinity of ATC installations with common access roads, parking and drainage facilities, and low voltage power supply, and will use some common equipment (e.g., duct banks, under-track crossings etc.), hence these should be designed and installed in consultation with the ATC System. The secure mounting of enclosures and equipment along the ROW shall be accomplished in accordance with the *Structures* chapter of these Design Criteria. The number of WPC at each site will depend upon the site conditions, the layout of track (including crossovers and MODs), the location of the auxiliary power source, and the routing of cables. The requirement and locations of WPC shall be suitably optimized in consultation with the OCS, ATC, and Communications Systems.

The design of each WPC shall include:

- All equipment provided therein
- Its grounding system

[22] This has been agreed with the ATC group but its inclusion in the Contract Documents has yet to be confirmed.

- SCADA interface with the communications system
- Auxiliary power and SCADA interface with the OCS system at the operating panel of the MOD
- Foundations

20.13 Calculations

These requirements have been specified in other Contract Documents.[23]

20.14 New Power Utility Services

20.14.1 115 kV/230 kV ac, Single-Phase 60 Hz Services

The design of the traction power substations and the associated interfaces to the power utility service provider shall comply with the latest version of the codes and standards specified elsewhere in this chapter.

At some locations, the TPS design shall also include full (or partial) design of the HV power utility switching stations and/or the HV interconnections to the traction substations. Refer to the Contract Documents for these requirements.

The power utility services have been identified and described in the Facility Interconnection Studies by the local power utility service providers (see Section 20.5, Related Documentation).

The following requirements shall apply:

- The capacity of each incoming power service shall be sufficient to support the following:
  - Full service for the ultimate design headway under normal operation and single electrical contingency mode of operation (see Section 20.3.2.2, in Description of TES, TPS Performance Requirements).
  - No disruption to (but reduced) services under double contingency mode of operation that includes the outage of an entire substations (see Section 20.3.2.2, in Description of TES, TPS Performance Requirements).
- The incoming power services to the SS shall meet the following conditions:
  - Two reliable HV power services, as independent as practical, supplied from separate utility transformers or buses
  - The power services to adjacent SS are to be from different transmission lines, supplied from different utility substations

[23] In TPS Performance Specifications

- Where one or more of these conditions cannot be met due to capital costs, and/or existing limitations on the concerned power utility transmission network, the issue shall be discussed with the Authority for approval to deviate from the specified requirements[24]

20.14.2 Auxiliary Power Services

The design of the TPS and the associated interfaces to the power utility shall comply with the latest version of the codes and standards specified elsewhere in this chapter.

See Section 20.9.13, Auxiliary and Control Power, for additional requirements.

20.15 Spares

All control, signal, and communication installations shall include at least 10 percent spare conductors and/or fiber strands.

All panel-boards and termination cabinets shall include at least 20 percent spare capacity for future growth.

All ductbank systems shall include at least 1 spare conduit or 20 percent spare conduits, whichever is greater. All spares shall be capped with a pull line/rope secured inside.

Cable tray system shall be sized to include 20 percent spare capacity.

The minimum level of spares for all major equipment and general consumables shall be prescribed by the TPS Designer during the design phase.

Spare provisions, associated with incoming power services, shall be coordinated with the respective power supply utility, and reviewed and approved by the Authority.[25]

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[24] A case of “Design Variance.”

[25] It is NOT a case of “self-certification.”

Chapter 21

Overhead Traction System and Traction Power Return System

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Revision	Date	Description
0	02 Mar 12	Initial Release, R0
0.1	Dec 2012	EXECUTION VERSION

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Acronyms

ACSR	Aluminum Conductor Steel Reinforced
EMC	Electromagnetic Compatibility
HST	High-Speed Train
NESC	National Electrical Safety Code
OCS	Overhead Contact System
PS	Paralleling Station
SCADA	Supervisory Control and Data Acquisition
SS	Substation
SWS	Switching Station
TES	Traction Electrification System
TPF	Traction Power Facility

21 Overhead Contact System and Traction Power Return System

21.1 Scope

These criteria detail the overhead contact system (OCS), and the traction return system, including the parallel negative feeders.

The OCS is a system in which electrical conductors are supported aerially above the Authority's right-of-way, generally by means of insulators and appropriate mechanical support arms or brackets, and which supplies electrical energy from the traction power supply facilities to rail mounted, electrically-powered vehicles through onboard, roof-mounted current collection equipment (pantographs). The OCS comprises the following:

- All overhead wiring, including the messenger wires, stitch wires, and contact wires, mounted on OCS support structures or brackets;
- The foundations, supporting structures, and any components supporting, registering, terminating or insulating the conductors;
- Insulators, neutral-sections, auto-tensioning devices, and other overhead line hardware and fittings;
- Equipment mounted on the supports for feeding, switching, detection or protection;
- Overhead conductor rails and their insulated support arrangements (if used) in very restricted clearance locations.

The traction return system is the means by which traction current is returned from the wheel-sets of traction units to the traction power facilities of the electrified railway track, comprising the negative feeders (due to the configuration of the autotransformer connections), the grounded running rails, aerial static wires (and buried ground conductors), together with all return current bonding and grounding interconnections. Grounding and bonding and lightning protection for the electrified railway is covered in the *Grounding and Bonding Requirements* chapter.

In an auto-transformer feed system, the feeder (often termed the negative feeder) is a paralleling conductor that is electrically separate from the catenary conductors over the tracks. This parallel (negative) feeder connects successive feeding points, and is connected, via circuit breakers and/or disconnect switches, to one terminal of a main power supply transformer or autotransformer in the traction power facilities. At these facilities, the other terminal of the transformers is connected to an OCS section or sections, via circuit breakers or disconnect switches.

21.2 Regulations, Codes, Standards, and Guidelines

Refer to the *General* chapter for requirements pertaining to regulations, codes, and standards.

- American Railway Engineering and Maintenance-of-Way Association (AREMA) Manual for Railway Engineering, 2009, Chapter 33 Electrical Energy Utilization
- European Committee for Electrotechnical Standardization (CENELEC) Standards
  - EN 50119, 2001, Electric Traction Overhead Contact Lines
  - EN 50122-1 Part 1, 1998, Protective Provisions Relating to Electrical Safety and Earthing
  - EN 50124-1, 2001, Insulation Coordination: Part 1 – Basic Requirements
  - EN 50149, 2001, Electric Traction: Copper and Copper Alloy Grooved Contact Wires
  - EN 50206, 1999, Pantographs: Characteristics and Tests
  - EN 50317, 2002, Requirements for and Validation of Measurements of the Dynamic Interaction between Pantograph and Overhead Contact Line
  - EN 50318, 2002, Validation of Simulation of the Dynamic Interaction between Pantograph and Overhead Contact Line
  - EN 50367, 2006, Technical Criteria for the Interaction between Pantograph and Overhead Line
- California Code of Regulations (CCR) Title 8, Division 1, Chapter 4, Subchapter 5: Electrical Safety Orders
- Institute of Electrical and Electronics Engineers (IEEE)
  - IEEE C2, 2007, National Electrical Safety Code
  - IEEE 80, 2000, Guide for Safety in AC Substation Grounding
  - IEEE 142, 1991, Recommended Practice for Grounding of Industrial and Commercial Power Systems
- California Public Utilities Commission (CPUC) General Orders (GOs)
  - CPUC GO 26-D, 1981, Regulations Governing Clearances on Railroads and Street Railroads with Reference to Side and Overhead Structure Parallel Tracks, Crossings of Public Roads, Highways and Streets
  - CPUC GO 95, 2006, Rules for Overhead Electric Line Construction
  - CPUC GO 143-B, 2000, Safety Rules and Regulations Governing Light Rail Transit
- Technical Specification for Interoperability (TSI) Energy, 2008, Technical Specifications for the Interoperability of Electrical Energy Subsystems
- IEEE C2 - National Electrical Safety Code (NESC)

21.3 Definitions

Agency	The railroad or other jurisdictional entity that is responsible for the operation and maintenance of the railroad.
Barrier	Equipment provided to prevent entry by an unauthorized person to a restricted area, structure or building, which also provides physical protection against direct contact with energized parts from non-normal directions of access.
Bond	A bond is an electrical connection from one conductive element to another for the purpose of maintaining a common electrical potential (equi-potential).
Bonding Conductor	A conductor for ensuring equi-potential bonding.
Collector Head	That part of the pantograph which runs under and in contact with, and collects current from the overhead contact wire or conductor rail.
Cross Bond	An electrical bond that interconnects the running rails which, in signalized territory, must be connected through impedance bonds.
De-energized	Electrical apparatus, such as overhead wires, substation conductors, cables, switches and circuit breakers, which is disconnected from its electrical power source(s), but which is not necessarily grounded. Note: This does not imply or ensure a safe state.
Direct Contact	Contact with energized parts.
Direct Feed System	A traction power feeding system in which the transformers are fitted with a single secondary winding having two terminals. One terminal is connected to the running rails/ground and the other to the catenary conductors over the tracks.
Direct Traction System Grounding	The direct connection between conductive parts and the traction system ground. Note: Grounding via impedance bonds, required by reason of signaling system track circuit considerations, is considered to be direct grounding.
Effectively Grounded	Intentionally connected to earth through a ground connection or connections of sufficiently low impedance and having sufficient current-carrying capacity to limit the build-up of voltages to levels below which undue hazards to persons or to connected equipment may result.

Electrical Section or Feed Section	The section between the phase break of the traction power substation and the phase break of the adjacent switching station that is normally fed by one main transformer of the substation.
Elementary Electrical Section	A section of the OCS traction power distribution system that can be isolated from other sections or feeders to the system by means of disconnect switches and/or circuit breakers.
Electric Shock	The effect of an electric current passing through the human body.
Energized	Electrical apparatus, such as overhead wires, substation conductors, cable, disconnect switches, and circuit breakers, which is connected to an electric power source.
Energized Part	An energized part is a conductor or conductive part that is energized under normal service conditions, but does not include the running rails or parts connected to them. Energized parts include roof-mounted equipment on electric vehicles, such as pantographs, train line conductors, and resistor units. The full length of insulators connected to energized parts shall be classified as energized when considering electrical clearance requirements.
Fault Condition	The presence of an unintended and undesirable conductive path in an electric power system.
Feeder	A current-carrying electrical connection, energized at high voltage (HV), between a traction power facility (substation, paralleling station or switching station) and the catenary conductors, which is energized at high voltage (HV) – 25 kV nominal, and is supported on the same structure as the catenary and static wire. 1. In an auto-transformer feed system, the feeder (often termed the negative feeder) is a paralleling conductor that is electrically separate from the catenary conductors over the tracks. This parallel (negative) feeder connects successive feeding points, and is connected, via a circuit breaker(s) and/or disconnect switch(es) to one HV terminal of a main power supply transformer or an auto-transformer in the traction power facilities. At these facilities, the other HV terminal of the main power supply transformer or auto-transformer is connected to a catenary section or sections, via circuit breakers or disconnect switches. 2. In a direct feed system, the feeder is a paralleling conductor that can be connected at frequent intervals to the OCS to provide localized electrical reinforcement of the circuit by increasing the effective cross-sectional area of the electrical system in that section.

Grounding Conductor	A conductor that is used to connect equipment or wiring systems to a ground electrode or ground grid.
High Voltage (HV)	A nominal voltage of 600 Volts or more.
Leakage Current	A current that flows to ground or to extraneous conductive parts, following a path or paths other than the normal intended path, but which is not of sufficient magnitude to create a fault.
Metal-to-Metal Touch Voltage	The difference in electrical potential between metallic objects or structures that may be bridged by direct hand-to-hand or hand-to-feet contact.
Non-Current-Carrying Parts	Metallic parts within the Authority's right-of-way which do not normally carry load currents or return currents.
Overhead Conductor Rail	A rigid metallic conductor, which substitutes for the contact wire and is mounted on insulators under a fixed overhead structure.
Paved Areas	In selected areas of maintenance facilities, yards and shops, the trackway may be paved to the upper level of the running rails to provide for the crossing of maintenance vehicles over the tracks and under the overhead conductors. Note: Where railroads support high-speed operations, at-grade crossings of any description are not permitted.
Rail Joint Bond	A conductor that ensures the electrical continuity of a running rail at an uninsulated, bolted rail joint.
Rail Potential	The voltage between running rails and ground due to traction return or fault current flowing in the rails.
Rail to Ground Resistance	The electrical resistance between the running rails and the earth.
Railroad or Railway Environment	The area adjacent to the running rails that is subject to the noise, vibration and air pressure of trains operating at high speed, and to the effects of the voltages, currents and electric fields associated with a 25 kV ac TES.
Rake	A preset lean of an OCS pole from vertical.

Regenerative Braking	A system in which the drive motors of the electric vehicles operate as generators and provide dynamic braking of the vehicle, while at the same time returning power to the OCS that can be used by receptive vehicles on the system or can be returned to the utility at the traction power substations.
Return Cable	A conductor that forms part of the TES return circuit, and which connects the rest of the return circuit to the substation.
Right of Way classification	Right-of-Way (ROW) classifications are defined in CPUC GO No. 143-B Rule 9.04 1. Exclusive - a railroad or railway right-of-way without at-grade crossings, which is grade-separated or protected by a fence or substantial barrier, as appropriate to the location (including subways and aerial structures). Note: This is the only type of ROW that is acceptable for the operation of trains at speeds in excess of 125 mph (200 km/hr). 2. Semi-Exclusive - exclusive right-of-way with at-grade crossings, protected between crossings by a fence or substantial barrier, as appropriate to the location. Note: This type of ROW is not suitable for high-speed operations in excess of 125 mph (200 km/hr), since at-grade crossings of the high-speed tracks cannot be permitted in accordance with FRA regulations.
Running Rails	The steel rails on which the rail vehicles run and which, in an electrified system, form part of the traction return circuit. The running rails may also be used for signal system track circuits, in which case special measures must be implemented to permit joint use with electrification.
Screen	A barrier that prevents unintentional direct contact with energized parts but will not totally prevent direct contact by deliberate action.
Short Circuit	A conductive path between energized and grounded components which may result in a high fault current. Note: Any such conductive path whether between conductors or between a conductor and ground is regarded as a short circuit.
Short Circuit Current or Fault Current	The electric current flowing through the short circuit or fault path.
Standing Surface	Any point on a surface where persons may stand or walk.

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Step and Touch Potential or Voltage	Refer to Metal-to-Metal Touch Voltage, Step Voltage, and Touch Voltage.
Stitch wire	The stitch wire is a supplementary tensioned conductor that is attached to the messenger wire and positioned at the supports with hangers supporting the contact wire. The spring effect of the stitch wire and hanger arrangement enhances the elasticity of the catenary at the support and provides for a better match with the mid-span elasticity of the catenary, thereby providing improvement in the quality of the current collection.
Stray Current	A current which follows a path or paths other than the intended electrical path (see Leakage Current).
Supports	The structural elements that support the conductors and their associated line hardware and insulators in an OCS.
Surge Arrester or Surge Suppressor	A protective device for limiting surge voltages on equipment by discharging or by-passing surge current; it limits the flow of power follow-on current to ground, and is capable of repeating these functions. Note: Sometimes referred to as a Lightning Arrester.
Traction Power Substation (SS)	An electrical installation that supplies traction power to the OCS and at which the voltage of the primary utility supply system is transformed to the OCS voltage.
Traction Return Current	The sum of the currents returning to the supply source (i.e., the substation).
Traction System Ground	The traction system ground consists of the running rails, the aerial static wires and all conductive parts connected thereto and which are solidly connected to ground.
Traction System Grounding	Connection between non-energized metallic parts and the traction system ground.
Tunnel Ground	The electrical interconnection of the reinforcing steel in reinforced concrete tunnels and, in the case of other modes of construction, the conductive interconnection of the metallic parts of the tunnel. Note: In the case of single-phase ac traction systems, the tunnel ground is connected to the running rails and thus forms part of the traction system ground which may be supplemented by external ground connections to earth.

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Voltage-limiting Device	A protective device which operates to prevent the permanent existence of a dangerously high step or touch voltage.

21.4 Overhead Contact System Description and General Performance Requirements

In order to minimize the number of substations and Electromagnetic Compatibility (EMC) problems along the alignment, the line will be fed by a 2x25 kV, 60 Hz autotransformer power supply system, utilizing traction power substations, switching stations and paralleling stations.

The Traction Power Substations (SS) will be connected to HV utility supplies and spaced approximately every 30 miles (48 km), while the Switching Stations (SWS) will be spaced at approximately mid distance between SS, i.e., at about 15 miles (24 km) from each SS, and the Paralleling Stations (PS) will be spaced at approximately 5 mile (8 km) intervals. At the PS and SWS locations, the autotransformers will parallel the Track 1 and Track 2 power supplies and balance the two 25 kV supplies (longitudinal parallel negative feeder and catenary) with respect to each other.

The OCS shall support voltage variations in accordance with IEC 60850 “Supply Voltages of Traction Systems”, as given in Table 21-1.

Table 21-1: Traction Power System Voltages

Voltage Condition	Symbol	Voltage
Operating nominal system voltage		25.0 kV
Highest permanent voltage	U_{max1}	27.5 kV
Highest non-permanent voltage	U_{max2}	29.0 kV
Lowest permanent voltage	U_{min1}	19.0 kV
Lowest non-permanent voltage	U_{min2}	17.5 kV

In addition, the maximum short circuit current shall be 15 kA for protection measurement purpose and accordingly for specification of the electrical equipment.

At all traction power supply stations the center tap of the respective supply transformer or auto-transformer will be connected to and referenced to the running rails, which will nominally be at ground potential.

The OCS will provide electric traction power to the pantographs of the electric trains using the route and will, therefore, be configured as a 25 kV-0-25 kV arrangement with the catenary at a nominal voltage of 25 kV to ground and the longitudinal parallel negative feeder also at a nominal voltage of 25 kV to ground, but in phase opposition to the catenary. There is a 180

degree phase difference between the voltages of the parallel negative feeders and the OCS, giving a 50 kV phase-to-phase voltage difference between these conductors. The OCS shall transfer electric power from the Traction Power Substations to the trains under all operating conditions and shall provide for reliable operation under the environmental conditions detailed in Section 21.5.

Except at Phase Breaks, the OCS shall provide for uninterrupted traction power collection at the maximum operating speed of 220 mph (354 km/hr).

To allow bi-directional working, enabling trains to continue operation under emergency conditions and to facilitate routine OCS maintenance, the OCS shall be divided into electrical sections and sub-sections. The OCS shall be sectionalized as indicated in Section 21.12 below.

To facilitate operations and maintenance activities, the OCS shall typically be equipped with non-load break motor operated disconnect switches at feeding points, which can be operated both locally on site and remotely through a supervisory control and data acquisition (SCADA) system. The switches shall be fitted with OCS voltage detection circuitry that will provide for remote monitoring of the system.

The OCS phase break arrangements shall be located at SWSs and, as required, at SS to electrically separate two successive catenary electrical sections fed from different 25 kV ac sources; i.e., not of the same phase. The electric trains shall pass through each phase break arrangement without establishing an electrical connection between the successive electrical sections which are fed from different phases. This shall be achieved at the designated maximum operating speed with the train pantographs raised and in contact with overhead contact wire, but with the pantograph breakers off.

Rail Return shall primarily be through the running rails, but a Static Wire (ground wire) shall be provided that interconnects all OCS support structures – poles, portal structures, wall brackets, tunnel drop pipes, etc. – which shall be connected via impedance bonds to the running rails and to the ground grid at each traction power facility (TPF). Other cross-bonding connections may be required to minimize rail potential rise, and the frequency and location of these connections and of the impedance bonds shall be determined under the TP system design and coordinated with the ATC System design – refer to the *Grounding and Bonding Requirements* chapter. In electrical sections remote from sections in which trains are operating, the parallel negative feeder effectively carries much of the return current and minimizes the amount that flows through the rails and static wires.

For a more comprehensive description of the traction power supply system and its associated facilities, refer to the *Traction Power Supply System* chapter.

21.5 Environmental Conditions and Climatic Loading Requirements

Information on climatic and environmental conditions in the corridor are given in the *General* chapter with data listed on a segment-by-segment basis. The OCS shall be designed on a system-wide basis to provide for reliable operation under the following environmental and climatic conditions:

21.5.1 Humidity

The OCS shall operate without failure or deterioration in all humidity conditions found in California. These include 100 percent humidity, including rain, heavy fog and salt-laden atmospheres in sections of the route near the ocean, and 100 percent humidity in tunnels.

21.5.2 Ice

Reference to Figure 7.1 ''Ground Snow Loads'' of the ASCE Standard "Minimum Design Loads for Building Structures" indicates limited snow falls and formation of ice along the alignment. In accordance with Table 250-1 and Figure 250-3(a) of the National Electrical Safety Code (NESC), the OCS design shall not consider ice loading.

21.5.3 Wind

The ASCE Standard "Minimum Design Loads for Building Structures" defines the basic wind speed corresponding to the wind load for wind force resisting structures as a 3 second gust speed at 33 feet (10.06 m) above ground for open terrain, Exposure C, associated with an annual probability of 0.02 (50 year mean recurrence interval) of being equaled or exceeded. This basic wind speed, in accordance with Figure 6-1 of the ASCE Standard, is V_{bws} = 85 mph (38 m/s) for the State of California. This 3 second gust speed corresponds to a mean maximum hourly wind speed of [V_{bws}/1.52 =] 56 mph (25 m/s) approximately.

In accordance with Section 4.2.2 of Chapter 33 of the AREMA Manual, two different wind speeds, the operational wind speed and the design wind speed shall be used for OCS design:

- The operational wind speed shall be used to compute catenary support loading, catenary wire displacement for pantograph security, and permissible maximum span lengths, and will be taken as V_{op} = 60 mph (26.8 m/s).
- The design wind speed shall be used to determine the ultimate strength requirements of the OCS and will be taken as V_{bws} = 85 mph (38 m/s) corresponding to the ASCE and NESC basic wind speed for the route.

The wind velocity pressure q_z shall be calculated by the NESC formula:

$$q_z = 0.00256\, V^2\, K_z\, G_{RF}\, I\, Cf\, A \quad \text{in lb/sq ft.}$$

which is equivalent to

$$q_z = 0.613\, V^2\, K_z\, G_{RF}\, I\, C_f\, A \qquad \text{in N/m}^2$$

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Where:

- 0.00256 (0.613 metric) is the velocity pressure numerical coefficient reflecting the mass density of air for the standard atmosphere
- K_z is the velocity pressure exposure coefficient
- V is the basic wind speed = 3 second gust wind speed at 33 feet (10.06 m) above ground for open terrain, Exposure C; i.e. V_{bws} in mph (m/s)
- G_{RF} is gust response factor
- I is the importance factor (I being equal to 1.00 for OCS)
- C_f is the force coefficient shape factor
- A is the projected wind area

Note: K_z, V and G_{RF} are based on open terrain with scattered obstructions (Exposure Category C as defined by ASCE, and are used as the basis for the NESC extreme wind criteria). For very exposed areas, the wind velocity pressure shall be increased by the ASCE factor K_{zt}.

For OCS structural calculations, loads due to wind shall be multiplied by the load factors given in NESC Table 253-1. The effects of wind pressure on OCS poles, due to slipstream effects caused by the proximity to high-speed trains operating at speeds in excess of 125 mph (200 km/hr), shall also be considered.

21.5.4 Atmospheric Pollution

The OCS equipment shall be resistant to polluted atmospheres, such as may occur in highly industrialized areas, salt-laden marine atmospheres near the ocean, and persistent fog. In addition, the OCS equipment shall be resistant to the corrosive atmospheres that may be found in tunnels and cut-and-cover structures.

21.5.5 Ambient Temperatures Range

General: In developing the settings for the auto-tensioning devices (balance weight anchor arrangements, the designer shall take into consideration the typical and extreme ambient temperatures, as recorded on a segment-by-segment basis along the route.

Tunnels: For long tunnels, only the first 1300 ft. (396 m) of catenary from each portal shall be considered subject to external ambient temperature variations. For the balance of the tunnel length inside the 1300 ft. (396 m) limits, the designer shall confirm the probable ambient temperature range, which may differ from the external range, and shall use the identified range for the tunnel OCS design.

21.5.6 Conductor Wire Temperature Range

General: Based on the initial analyses, the messenger and contact wires and the parallel feeder conductors are likely to reach a maximum operating temperature of 176°F (80°C) in above grade sections and for the first 1300 feet (396 m) in tunnels.

21.5.7 Conductor Tensioning

General: The mechanical tensions in the messenger and contact wires shall be maintained automatically throughout the temperature ranges specified above.
The designer shall confirm the probable maximum conductor temperatures in the tunnels, which shall be used for OCS tensioning and support system design.

21.6 Overhead Contact Line Design

The OCS shall be of a proven design that is capable of sustaining satisfactory current collection for train operations at 220 mph (354 km/hr).

The OCS system designer shall be cognizant of and shall incorporate into the OCS design the fundamental design data and performance instructions, as defined in these Design Criteria, which include the following:

- Service and operations information
- Infrastructure characteristics
- Vehicle characteristics
- Pantograph characteristics
- Traction power system design
- Environmental conditions
- External limitations on contact wire height, uplift, system height, and/or clearances
- Life expectancy and desired maintenance/renewal philosophy for all components, plus allowable grooved contact wire wear
- Specification of EMC limitations

It is vital that the OCS design be coordinated with the pantograph and rolling stock designs, refer to the *Rolling Stock* chapter, since one of the most critical aspects in the development of the OCS design is the dynamic performance of the overhead contact line and the need to achieve good quality current collection at high operating speeds. The principal measure of this aspect is loss of contact between the pantograph strip and the contact wire which must be minimized. In order to minimize contact loss and the creation of arcs, the designer shall comply with the requirements for dynamic behavior and quality of current collection as detailed in the following sections.

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Other important aspects of the design are the provision of adequate clearances or provision of protective barriers and screens, together with effective grounding and bonding of the electrical system and wayside metallic objects, which are required to minimize safety hazards.

The recommended minimum clearances between energized parts and grounded parts are detailed in Section 21.14.8. The location of OCS equipment, including poles and downguys, shall be coordinated with clearances defined in the *Utilities* chapter.

21.6.1 Geometry of the Overhead Contact Line

The OCS shall consist of a simple, stitched auto-tensioned catenary system, using a bare hard-drawn copper, bronze or other copper alloy messenger wire supporting a nominally level (no pre-sag), solid copper alloy contact wire by means of copper alloy current carrying hangers.

In general, the catenary shall be supported by pole mounted cantilever frames which shall be designed to provide the required system height and to register the correct stagger of the wires relative to the track centerline. The messenger wire shall be positioned vertically (plumb) above the contact wire. Back-to-back cantilevers, supported on single poles centered between tracks, shall not be used for the high-speed main tracks, except in station areas where their use will be permitted between a through-line and a station platform track.

An aerial Static Wire (ground wire), connected at regular intervals to the track via impedance bonds, shall be run alongside the catenary to interconnect each OCS support structure and bracket, such that all OCS non-live metallic supports are at the same ground (and track) reference potential.

The longitudinal negative feeder shall be supported near the top of the OCS poles, preferably on the track side, but may be positioned on the field side where the Authority's right-of-way width or overhead structure configuration dictates.

The aerial parallel negative feeders, and the aerial static/ground wires which connect all OCS supporting structures, shall both be fixed termination bare ACSR (Aluminum Conductor Steel Reinforced) conductors, except where local site conditions (reduced clearances, etc.) dictate the need to use insulated cables for the negative feeders.

The method of auto-tensioning the messenger wire and contact wire shall be by balance weight and pulley tensioning devices. The tensions shall be applied to the contact and messenger wires individually, using separate balance weights, tensioning devices and anchoring positions.

The designer shall evaluate overlap arrangements but the initial analyses indicate that the overlaps should comprise a 5-span configuration.

Maximum tension lengths from anchor to anchor shall not exceed 4,600 feet (1,400 m) in open route sections and 4,000 feet (1,220 m) in tunnels and adjacent to traction power substations and switching stations. Exceptions up to 5,000 feet (1,525 m) may be allowed on a case-by-case basis. At approximately mid-distance between auto-tension terminations, mid-point anchor

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arrangements shall be installed, such that the maximum half tension lengths do not exceed 2,300 feet (700 m) in open route sections and 2,000 feet (610 m) in tunnels and at power supply stations and switching stations.

The maximum permissible span length between supports shall be determined using appropriate computer software programs, which shall take into consideration the permissible working range of the pantograph and allowable lateral displacement of the contact wire under the designated operating conditions, including dynamic movement of the vehicle and pantograph. The programs shall be fully validated and back-up hand calculations shall be furnished. The maximum permissible span differential (difference in adjacent span lengths) shall be no more than 33 feet (10 m), with the proviso that, if the dynamic pantograph-OCS simulation results (detailed below) indicate other values may be more appropriate, these shall be adopted.

At overlap locations where sectionalizing is not required, uninsulated mechanical overlaps shall be installed that will permit the pantographs to transition smoothly from one tension length to the next under power.

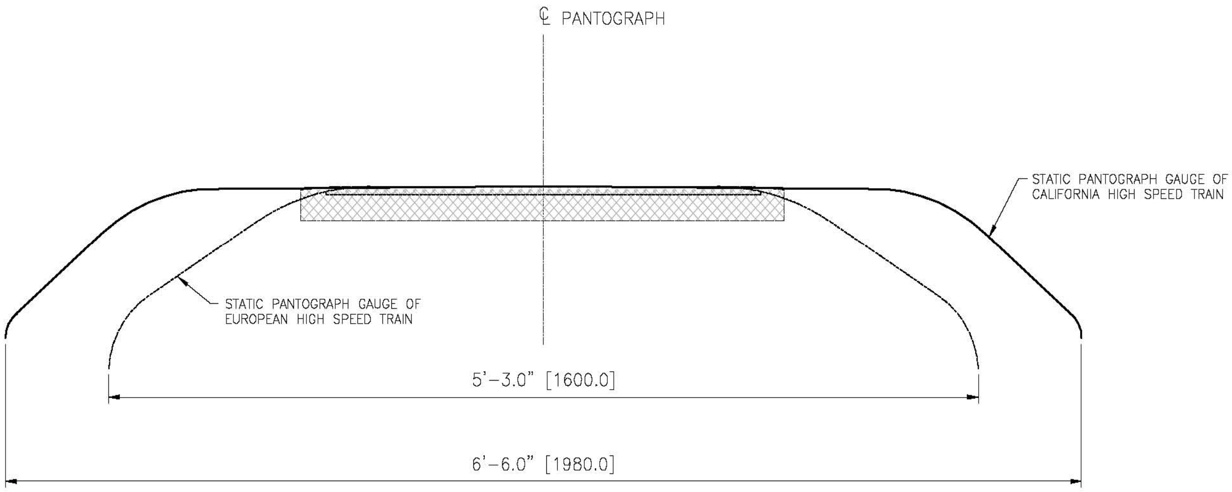
Wherever practicable, the OCS shall be free running under overhead bridges, i.e., no OCS or feeder support attachments under the structure. New bridges shall be designed to accommodate a free-running clearance height. Existing bridge clearances, if any, shall be reviewed to determine whether free-running OCS arrangements can be accommodated, which is the goal. The designer shall secure permits for attachments to any third party owned bridges or structures where it is determined that OCS support, registration or termination attachments will be required.

In tunnels, the OCS, feeders and static wires shall, wherever possible, be supported by cantilevers attached to soffit-mounted drop pipes, or from wall-mounted support brackets. The OCS system height and cantilever geometry will be dictated by the available headroom. In limited clearance locations, particularly at low headroom bridges or in cut-and-cover tunnels, resilient arms, supporting and registering both messenger and contact wires, may have to be utilized. If any extremely restricted clearance locations are identified, it may be necessary to adopt the use of conductor rail arrangements, but these should be avoided wherever possible.

21.6.2 Geometry of the Pantographs

The Overhead Contact Line shall be designed to accommodate pantographs with a pantograph head profile, as shown in Figure 21-1, which shall be based on the geometry detailed in EN 50367: 2006 Figure B.3, but having a maximum pantograph head width of 78 inches (1980 mm), and with horns made of insulating material. Based on the dynamic OCS-Pantograph simulations and other dynamic OCS analyses, the designer may determine that a narrower width pantograph is acceptable. Regardless, it shall not be smaller than the 5 feet 3 inch (1600 mm) European standard profile as shown in Figure A.7 in EN 50367: 2006.

Figure 21-1: Combined Pantograph - Maximum Static Geometry (mm)



Pantograph heads fitted with contact strips, having independent suspensions, shall remain compliant to the overall profile with a static contact force of 15.75 lbf (70 N) applied to the middle of the head.

The contact wire shall be installed and maintained at a nominal constant height of 17 feet 5 inches (5310 mm) at the supports on, where the maximum vehicle load gauge height will be 14 feet 9.25 inches (4500 mm), with a construction tolerance of ± 0.5 inch (±13 mm) subject to the proviso that the contact wire height difference at adjacent structures shall be less than ½ inch (13 mm) to ensure the near-constant contact wire height that is required for satisfactory current collection by pantographs at high speed.

The maximum permissible contact wire gradients and the corresponding maximum gradient changes shall not exceed, according to the maximum speed, the following values:

Table 21-2: Maximum Permissible Contact Wire Gradient versus Operating Speed

Maximum Speed (mph)	Maximum Speed (km/hr)	Maximum Contact Wire Gradient	Maximum Contact Wire Gradient Change
> 125	> 200	0	0
125	200	2/1000	1/1000
100	160	3.3/1000	1.7/1000
75	120	4/1000	2/1000
60	96	6/1000	3/1000
45	72	8/1000	4/1000
30	48	13/1000	6.5/1000

On tangent track (straight track), the contact wire shall be staggered at each location to alternate sides of the pantograph center line, and the stagger shall normally be set at ±12 inches (±305 mm). On curved track, the staggers shall be calculated on a case by case basis taking into account the track superelevation, radius of curvature, and wind speed, but shall not exceed 15 inches (380 mm). Registration elements – steady arms, contact wire clips, etc. – shall be as light as possible to minimize the possibility of creating a hard spot in the contact wire.

For pantograph security purposes, the permissible lateral deflection of the contact wire under the action of crosswind (defined as the maximum operational wind speed for which unrestricted train operations will be permitted) shall be the smaller of ≤ 15¾ inches (400 mm) or (55-L2) inches [(1.4–L2) m] for the 1600 mm (5 feet 3 inch) wide pantograph, as specified in ENE 4.2.9.2, where L2 is the half-width of the dynamic envelope of the pantograph passage (as defined in Appendix A.3 of EN 50367: 2006). If a pantograph width other than 1600 mm (5 feet 3 inch) is to be used, the 55 inch (1.4 m) dimension shall be adjusted.

21.6.3 Compliance of the Overhead Contact Line System with the Infrastructure Gauge

The OCS design shall comply with the static and kinematic envelopes, as defined in the *Trackway Clearances* chapter, for vehicles which will run on the dedicated high-speed train tracks.

The design of civil structures shall take into account the space necessary for the passage of pantographs in contact with the overhead line equipment and for installation of the OCS itself, as shown in Figures 21-9, 21-10 and 21-11. The dimensions of tunnels and other structures shall be mutually compatible with the geometry of OCS and the kinematic envelope of the pantograph, the static profile of which is shown in Figure 21-1.

21.7 Conductor Tensions

The permissible tensile loading of the wires and ropes to be used shall consider the weighted parameters, as indicated in EN 50119: 2001, clauses 5.2.4, 5.2.5, and 5.2.6, which include maximum working temperature (excluding short circuit loading), allowable wear, wind and ice loads, tensioning accuracy and efficiency, termination fitting effects, welded or soldered joint effects, and creep, as applicable. In addition, the current heating effects of short circuit faults, occurring during peak operations shall be assessed to ensure that the maximum permissible conductor temperatures are unlikely to be exceeded.

21.8 Catenary Conductors

Initial analyses have shown that the following conductors form a viable catenary. The designer shall confirm conductor sizes and material selection as defined in these criteria. The same conductor and cable types and sizes shall be used throughout the entire system.

21.8.1 Contact Wire

The proposed contact wire is a 150 mm^2 (approximately 300 kcmil equivalent) grooved copper-magnesium alloy wire, designated CuMg 0.5 BC-150 that shall comply with the requirements of EN 50149: 2001 Clauses 4.1, 4.2, 4.5, 4.6 and 4.7, regarding the material designation and composition, conductor appearance and condition, clamping groove, electrical characteristics (resistivity, resistance per mile (km)), tensile strength and percentage elongation after fracture, breaking load, and mass of the wire. Joins shall be permitted in drawing stock or intermediate rod stock, as detailed in EN 50149: 2001 Clause 4.8, but no joints shall be made in the completed wire.

21.8.2 Messenger Wire

The proposed messenger wire is a 300 kcmil (approximately 150 mm^2 equivalent), 37-strand, hard drawn copper conductor conforming to ASTM B-1 and ASTM B-8 requirements. Subsitutes which can meet the electrical, mechanical requirements could be accepted, as detailed in Clause 21.6.1.

21.8.3 Stitch Wire

The proposed stitch wire is a 76 kcmil (approximately 38 mm^2 equivalent), 7-strand, hard drawn bronze conductor, Alloy 55, conforming to ASTM B-8 and ASTM B-105 requirements.

21.8.4 Hanger Wire

The designer shall select a suitable flexible conductor for the hanger wire which, together with the messenger wire and contact wire clips, shall provide an electrical connection between the messenger and contact wires.

21.8.5 Alternate Conductors

If the designer opts to use conductors other than those indicated above, the designer shall confirm conductor sizes and material selection as defined in these criteria. In addition, the designer shall require the manufacturer to provide conformity verifications, as detailed in EN 50149, during the production phase of all catenary wires.

21.9 Other Overhead Conductors and Cables

Insulated cables and conductors required by other disciplines, such as signal cable, signal-power cables, control wires and communications cables, will generally be installed underground but may, on occasions, have to be mounted aerially on the OCS poles.

These aerial conductors shall be mounted and spaced on the OCS support structures in accordance with the more stringent requirements of either the NESC or CPUC General Order rules, as they apply to each system classification. Mounting arrangements shall provide for the

safety of maintenance personnel. These cables and conductors shall be mounted and profiled in such a manner as to avoid the Overhead Contact Line Zone and Pantograph Zone (Figure 21-5) to the greatest extent practicable. Loading calculations and structural designs for the support of these cables and conductors shall comply with these design criteria.

Insulated cables and bare conductors, other than the catenary conductors identified above, that are associated with the OCS may parallel or cross the Authority’s right-of-way, including the parallel negative feeders, and static (ground) wires. Preliminary analyses have identified the following selections, which shall be confirmed by the designer:

21.9.1 Parallel Negative Feeder

In general, the parallel negative feeder shall be a bare stranded 556 kcmil ACSR “Eagle” conductor for use throughout the system. Since the mainline will be two-track, with platform tracks at intermediate stations, two negative feeders are to be installed; one on each side of the Authority’s right-of-way.

At locations where a bare conductor cannot be installed, appropriately sized insulated 25 kV cables with appropriate sealing ends shall be substituted and spliced into the bare conductor, which may or may not have to be terminated on a dead-end anchor pole.

21.9.2 Static (Ground) Wire

In general, the static wire shall be a bare stranded 4/0 ACSR “Penguin” for use throughout the system. Two static wires are to be installed - one on each side of the Authority’s right-of-way – interconnecting all metallic OCS support structures, including OCS poles and bridge and tunnel drop pipes and wall brackets, to provide a continuous ground connection.

21.9.3 Insulated 25 kV Cable

Power feeder cables, where used, shall be insulated with a black, low-smoke, flame-retardant, ozone-resistant, ethylene-propylene compound jacket and the conductor shall be coated, soft-drawn stranded copper, covered with a double-wrapped separator tape or extruded semi-conducting Ethylene propylene rubber (EPR) screen. Cables shall be sized to suit the identified ampacity requirements and installation location conditions.

21.9.4 Insulated Return Cable

Return cables, where used, shall be insulated with a black, low-smoke, flame-retardant, ozone-resistant, ethylene-propylene compound jacket and the conductor shall be coated, soft-drawn stranded copper, covered with a double-wrapped separator tape or extruded semi-conducting EPR screen. Cables shall be sized to suit the identified ampacity requirements and installation location conditions.

21.10 Dynamic Behavior and Quality of Current Collection

Good quality interactive dynamic performance with minimum wear can be assured by consideration of the quality of current collection, which has a fundamental impact on the life of the contact wire and pantograph components. Compliance with several measurable parameters, as detailed below, shall be achieved.

21.10.1 Requirements

The number of pantographs in service per train and the spacing between multiple pantographs is necessary to confirm the OCS phase break design arrangement. These factors have a significant impact on the quality of current collection, since each pantograph interacts dynamically through the OCS with the performance of other pantographs. This interaction is also affected by the wave propagation speed. The overhead contact line shall be designed for operation at the maximum line speed with two adjacent operating pantographs spaced at 656 feet (200 m) apart, as indicated in Section 21.12.2 below. The 656 feet (200 m) spacing shall be used in the OCS dynamic simulations, which shall be considered to be the conformity assessments for verifying compliance with the requirements for dynamic behavior and quality of current collection, as indicated in Table 21-3.

It is possible that more than one type of pantograph and current collector head may be supplied, particularly if rolling stock is procured from more than one supplier. In all cases, the pantograph shall be of proven design for very high speed performance and shall be equipped with a fail-safe device that will detect any failures of the contact strips or collector head, which will trigger automatic lowering of the pantograph. The pantograph shall also be equipped with an uplift limiting device (pantograph stop) and with insulated horns. It is recommended that a carbon-based material be selected for the collector strips to minimize wear of the contact wire and the supplier shall be required to demonstrate the compatibility of the collector strip material with the contact wire.

To achieve good quality current collection, loss of contact between the pantograph strip and the contact wire shall be minimized, since loss of contact can generate electric arcs which will cause rapid wear of both the contact wire and the pantograph head and collector strips, and may result in the creation of radio frequency interference and in the tripping of feeder circuit breakers (in the event of large arcs with excessive current draws for protracted durations due to significant contact loss). As indicated in EN 50367: 2006 Table 6, for sections dedicated to very high speed, the on-site measured arc percentage (NQ) shall be ≤ 0.2 percent at maximum line speed of 220 mph (354 km/hr. For any given vehicle speed, the minimum arc duration that is to be considered shall be 5 ms, and the arcing percentage characteristic (NQ) – also known as the contact loss percentage - is given in % by the EN 50367: 2006 Clause 3.16 formula:

$$NQ = \frac{\sum t_{arc}}{t_{total}} \times 100$$

Where:

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t_{arc} is the duration of an arc lasting longer 5 ms;

t_{total} is the measuring time with a current greater than 30% of the nominal current.

The goal of assessing the interactive dynamic behavior and its impacts on current collection is to ensure there is a continuous and uninterrupted power supply to the electric vehicles with minimal disturbances.

At the design stage, the quality of the OCS-pantograph current collection shall be assessed at the maximum operational speeds for all proposed combinations of rolling stock and pantograph by means of computerized dynamic simulation models. The output from these simulations shall provide determinations of the dynamic effects on the OCS, including values of the simulated contact forces, mean contact force (F_m), standard deviation (σ), statistical value $F_m–3\sigma$, contact loss percentage (NQ), and vertical movement of the contact point (contact wire uplift - S_0). The permissible allowances for these factors at maximum line speed are detailed in Table 21-3.

Table 21-3: Requirements for Dynamic Behavior and Current Collection Quality

Operating Requirement	> 125 mph (200 km/hr)
Allowance for Steady Arm Uplift	2 S_0
Mean Contact Force F_m (N)	See target curve below
Standard Deviation σ_{max} (N)	≤ 0.3 F_m
Percentage of Arcing - NQ (minimum duration of arc 5 ms)	≤ 0.2 %

21.10.2 Contact Wire Wave Propagation Speed

The speed of wave propagation in contact wires is a characteristic parameter that is used to assess the suitability of an overhead contact line for high-speed operation. This parameter depends upon the specific mass and the tensile stress in the contact wire.

Based on the recommendations of Clause 4.2.12 of the Energy TSI, the maximum operational line speed shall be not greater than 70 percent of the wave propagation speed. Therefore, the wave propagation speed shall be greater than 314 mph (505 km/hr) for the 220 mph (354 km/hr) maximum operating speed.

21.10.3 Static Contact Force

The pantograph static contact force is the mean vertical force exerted upward on the contact wire by the pantograph collector head, and is caused by the pantograph raising mechanism when the pantograph is raised and the vehicle is at a standstill.

The pantograph static force shall be adjustable between 9 and 27 pounds force (lbf) (40 and 120 N). The nominal static force shall be 15.75 (+4.5/-2.25) lbf (70 +20/-10 N), and the OCS shall be designed to suit this permissible range in the static contact force from 13.5 to 20.2 lbf (60 to 90 N). Only pantographs designed and proven for very high speed performance shall be permitted.

21.10.4 Mean Contact Force

The mean contact force is the dynamically corrected statistical mean value of the forces due to static and aerodynamic effects, which depend on the design of the pantograph and the nature of the current collector strips on the pantograph head. It is equal to the sum of the static contact force and the aerodynamic force, which is caused by airflow on the pantograph elements at the considered speed. The mean uplift force is a characteristic of the given rolling stock/pantograph combination. In this context, F_m represents a target value which should be achieved to ensure current collection without undue arcing, but which should not be exceeded to limit wear and hazards to the contact wire and the current collection strips.

The design of the overhead contact line equipment must allow for the maximum and minimum contact forces that occur between the pantograph and the contact wire, at the maximum permissible speed of the vehicle, while taking into account the aerodynamic effects. The minimum contact force shall always be positive to ensure no loss of contact between the pantograph and the overhead contact line. Force values vary with different combinations of rolling stock/pantograph and OCS.

The overhead contact line shall be designed to be capable of sustaining this level of force for all pantographs on a train.

In the case of trains with multiple pantographs simultaneously in operation, the mean contact force F_m for any pantograph shall be not higher than the target value, since the current collection criteria shall be met by each individual pantograph. The target value for the mean contact force F_m as a function of the running speed for ac systems is depicted in the following graphs - Figure 21-2 (lbf-mph) and Figure 21-3 (N-km/hr).

Figure 21-2: Target F_m Values (lbf-mph)

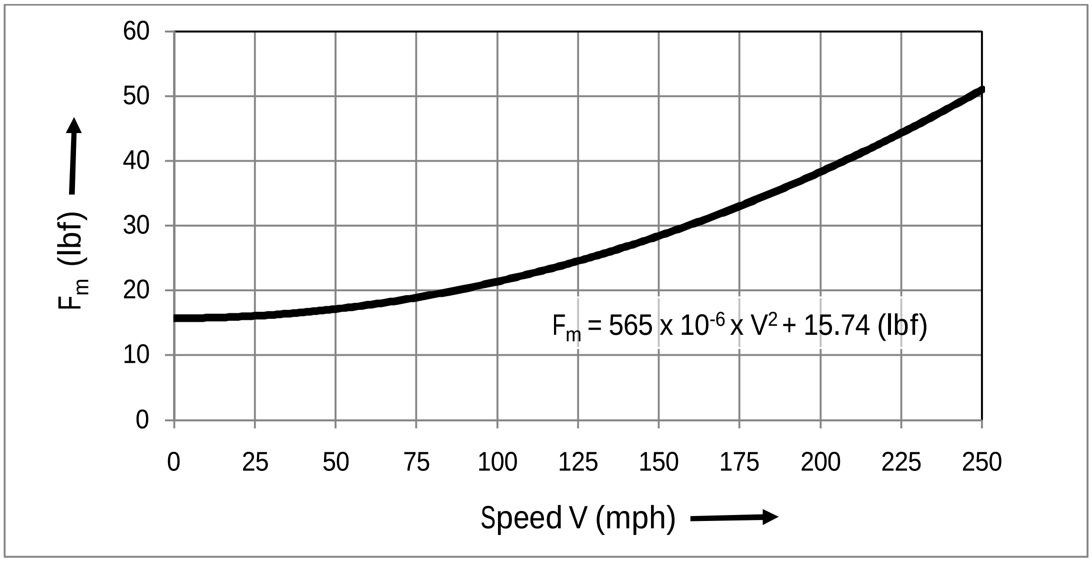
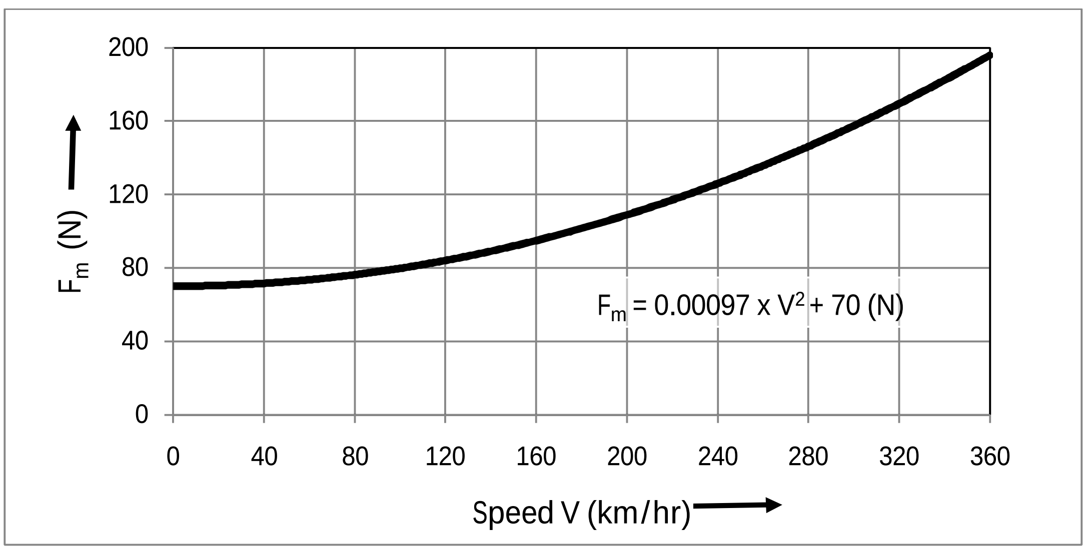


Figure 21-3: Target F_m Values (N-km/hr)



The maximum contact force (F_{max}) is normally within the range of $F_m+3\sigma$ (three standard deviations) for level grade open route sections. Higher values may occur elsewhere, but shall not exceed 79 lb (350 N) at speeds greater than 125 mph (200 km/hr) per EN 50119: 2001 Table 1.

The minimum permissible contact force is the force value at which loss of contact between the pantograph and contact wire is probable, and is represented by the statistical value $F_m–3\sigma$, which is a measure that permits the assessment of the consistency of contact between the pantograph and the OCS. The value $F_m–3\sigma$ must be positive to avoid contact loss.

21.10.5 Contact Wire Uplift or Vertical Movement of the Contact Point

The contact point is the point of mechanical contact between the pantograph contact strip and the contact wire.

The vertical height of the contact point above the track shall be as uniform as possible along the span length; this is essential for high-quality current collection. The maximum difference between the highest and the lowest dynamic contact point height within one span shall be less than 3.15 inches (80 mm) at the maximum operating speed of 220 mph (354 km/h). This value has been derived from the Energy TSI Clause 4.2.17 and Table 4.2.17 for Category I lines (as defined in the Energy TSI Clause 1.1).

During the design phase, the projected contact wire uplift (variation in dynamic contact point height) shall be verified by simulations in accordance with EN 50318: 2002. Uplift values shall be presented as a graph of the contact point vertical position against distance in the span to evaluate the extent of the vertical movement:

- for the maximum line speed of the overhead contact line,
- for the longest span length,
- using the mean contact force F_m (as detailed above).

After installation, uplift shall be validated by measurements in accordance with EN 50317:2002.

The variation in contact point height need not be verified for uninsulated or insulated overlap spans or for spans above track turnouts or crossovers.

In order to maximize safety under all operating conditions (including strong wind conditions and slight mis-adjustments of the pantographs), the dynamic pantograph envelope at the maximum operating speed shall consider twice the value of the estimated or simulated uplift S_0 at the support point. The design of the OCS cantilever and registration shall allow the uplifted steady arm to clear the dynamic pantograph envelope. For initial design purposes, a minimum uplift of 10 inches (250 mm) shall be assumed.

Uplift values shall be confirmed by simulation results (as indicated below) and, if multiple pantograph-train consists are furnished, the designs shall accommodate, as a minimum, the greatest simulated uplift values.

21.10.6 Conformity Assessment

Conformance with the above criteria shall be confirmed by the OCS supplier by means of dynamic interactive OCS-pantograph simulations and through equivalent records of on-site testing results for speeds above 220 mph (354 km/hr). Notwithstanding the above, the OCS shall be a proven system capable of sustaining satisfactory current collection for train operations at 220 mph (354 km/hr). The simulation program shall meet the validation requirements detailed in EN 50317: 2002 and EN 50318: 2002.

The final designs and specifications shall require that measurements (in accordance with EN 50317: 2002) of the interaction between the pantograph and the OCS shall be performed on the high-speed line during the testing and commissioning phase to check for correct installation and to prove the safety and the quality of the current collection system. These measurements shall be carried out with an approved pantograph, exhibiting the mean contact force characteristics for the envisaged design speed, installed on approved rolling stock. The installed overhead contact line shall be accepted if the measurement results comply with the requirements stipulated in Table 21-3 - Requirements for Dynamic Behavior and Current Collection Quality.

To check the performance capability of the current collection system, the following data, as a minimum, shall be measured:

- The contact force;
- The contact wire uplift at the support as the pantograph passes;
- The percentage of arcing and duration of arcs longer than 5 ms.

In addition to the measured values, the operating conditions (train speed, location, etc.) shall be recorded continuously, and the environmental conditions (rain, temperature, wind, tunnel, etc.) and details of the test configuration (parameters and arrangement of pantographs, type of OCS, etc.) during the measurement tests shall be recorded in the test report.

When or if changes from the equipment accepted and approved are proposed, such as the use of a pantograph of proven design that is to be installed on a new type of rolling stock, or a new OCS design for additions to or substitution of existing sections of the system, or a new pantograph design that is to be installed on the approved rolling stock, conformity assessment testing shall be carried out in accordance with EN 50317: 2002 and/or EN 50206-1: 1999, with particular emphasis on the mean contact force and loss of contact requirements. If the tests are passed successfully, the new OCS design, or the specific proposed pantograph / rolling stock combination, will be approved for use on the high-speed line.

21.11 Current Capacity of Overhead Contact System

As a minimum, the current-carrying capacity of the OCS shall comply with the current-draw requirements specified for the trains.

The OCS, including parallel feeders, return circuit conductors and feeder connections, shall be designed to cater to the electrical current loading under steady state peak period operating and fault conditions, as defined by the system design, under the environmental and climatic conditions defined in Section 21.5, with reference to the advisories contained in Annex A to EN 50119: 2001. In addition, the current heating effects of short circuit faults and durations, resulting from automated circuit breaker closure sequences (if adopted), which occur during peak operations shall be assessed.

The maximum temperature rise in the conductors, caused by the load currents, shall not lead to conductor temperatures at which the mechanical properties are impaired. The maximum permissible temperatures for bare conductors are given in the following table;

Table 21-4: Maximum Permissible Bare Conductor Temperatures

Conductor Material	Max. Temperature (^{0}F)	Max. Temperature (^{0}C)
Normal and high strength, high conductivity Copper	176^{0}F	80^{0}C
Silver Copper alloys	212^{0}F	100^{0}C
Cadmium Copper alloys	176^{0}F	80^{0}C
ACSR	212^{0}F	100^{0}C

The melting point of any grease used in the strands of the conductors shall be higher than the temperature limits specified above.

The designer shall undertake a design study to confirm the OCS complies with the specified requirements. Conformity assessment shall be carried out by design review.

21.12 Sectionalizing and Switching

To allow bi-directional working, enabling trains to continue operation under emergency conditions and to facilitate routine OCS maintenance, the OCS shall be divided into electrical sections and sub-sections. On the main tracks, only phase breaks (utilizing insulated overlaps) and insulated overlaps shall be used for power supply sectionalizing purposes. Mechanical section insulators will not be permitted except when used in the OCS above slow speed track turnouts and in the yard and shop areas.

To form the insulated overlaps, insulation shall be cut into the out-of-running sections of the messenger wire and contact wires of the two overlapping catenaries, having between them a limited air gap electrical clearance. The insulated overlap thus provides a sectionalizing point in the OCS as required for operational and maintenance reasons, but allows pantographs to transition smoothly from one energized electrical sub-section to the next under power.

21.12.1 Pantograph Spacing for Design of the Overhead Contact Line

The overhead contact line design shall be based on rolling stock operating with two raised pantographs spaced at 656 feet (200 m) apart for dynamic simulation assessments

21.12.2 Phase Breaks

The design of the OCS phase breaks shall permit approved trains to move at all speeds up to the designated maximum operating speeds from one electrical section to an adjacent electrical section without bridging between two electrical phases or two separate utility supply systems.

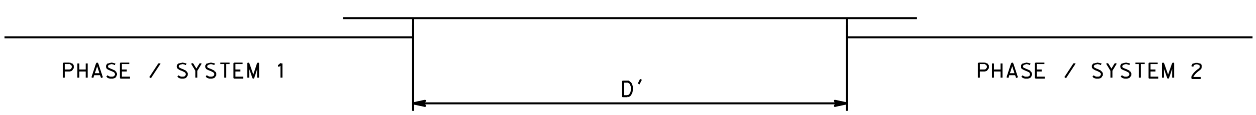
Trains shall traverse the entire phase break with pantographs raised and in contact with overhead contact wire, but with the pantograph breakers open.

Adequate means shall be provided to allow a train that is stopped within the phase break neutral section to be restarted and bidirectional movements shall be supported. The neutral section shall be configured such that it can be connected to, and energized from, either of the adjacent electrical sections by remotely controlled disconnect switches with the provision of appropriate interlocks to ensure the different phases cannot be inter-connected under any circumstances.

The geometry of the phase break elements shall prevent pantographs short-circuiting or bridging between power systems. Provision shall be made in the rolling stock design to avoid bridging of adjacent power supply systems should opening of the onboard circuit breaker(s) fail.

For high speed sections over 65 mph (104 km/hr), the Long Phase Break (Figure 21-4) has been selected. The long phase break design will allow all pantographs of the longest compliant trains to lie within the neutral section. The length of the neutral section shall be at least 1,320 feet (402 m).

Figure 21-4: The Long Phase Break



Conditions: D' > 1,320 ft (402 m)

21.12.3 OCS Sectionalizing in Tunnels

The designer shall coordinate the sectioning of the power supply system in each tunnel with the pertinent Agency, which will be responsible for development of the Tunnel Emergency Evacuation Plan. The sectioning shall be designed to support the overall strategy for evacuation from the tunnel.

Grounding devices shall be provided at tunnel portals and at tunnel access points, and close to the separation points between electrical sections. These shall be in the form of three-position disconnect switches, providing for Closed (inter-connection between adjacent electrical sections), Open (no electrical inter-connection), and Closed to Ground.

The disconnect switches shall be motorized and shall be both remotely and locally controlled fixed installations. Switch indication panels shall be provided at or adjacent to each switching location, indicating for the benefit of emergency response personnel the status of each switch and whether the OCS is energized / de-energized / grounded.

Procedures and responsibilities for grounding the OCS in tunnels by the Power Director or Power Dispatcher shall be defined in the emergency plan.

21.12.4 Disconnect Switches

To facilitate maintenance work and emergency operations, the OCS shall be equipped with disconnect switches at all primary feeding and by-pass feeding locations.

Where feasible, the OCS disconnect switches shall be pole-mounted at trackside and shall be single pole motorized switches capable of remote operation and also of local motorized or manual operation. The switches shall provide for isolation of discrete sections of the OCS (track), such that segments of the OCS can be de-energized for maintenance purposes. The disconnect switches shall also provide for by-pass feeding arrangements that can be implemented during emergency conditions to permit contingency modes of operation. Remote operation shall be performed from the Operations Control Center (OCC) and shall be accomplished using the SCADA system. OCS disconnect switches shall be of the no-load-break type and shall be rated for the system voltage and anticipated current loads, and shall be designed to carry the worst-case overload and short circuit currents without overheating. As a safety precaution, the switch operating mechanism shall be fitted with a locking bar that will permit the attachment of maintainer locks.

In general, the disconnect switches shall be of the two-position type, providing for Closed (inter-connection between adjacent electrical sections), or Open (no electrical inter-connection). For locations where solid grounding of the OCS is required, the OCS disconnect switches shall be of the three-position type, providing for Closed, Open, and Closed to Ground connections.

Where motorized disconnect switches are located in the vicinity of a traction power facility, the 125 V dc motor power shall be supplied from that facility. At remote locations, such as interlockings, the 125 V dc motor power shall be supplied from a wayside power control cubicle (WPC).

21.13 Insulation Coordination Requirements for OCS Installations

Insulation requirements for railroad electrification systems are covered by EN 50124-1: 2001 Railway Applications – Insulation Coordination – Part 1: Basic Requirements. Insulation coordination implies selection of the electrical insulation characteristic of the equipment with regard to its application and in relation to its surroundings. Insulation coordination can only be achieved if the design of the equipment is based on the stresses to which it is likely to be subjected during its anticipated lifetime. In accordance with EN 50124-1: 2001 Clause 2.2.2.1, the

OCS falls into either the OV3 or OV4 overvoltage categories for circuits that are powered by or from the overhead contact line, which are not protected against external or internal overvoltages and which may be endangered by lightning or switching overvoltages. For a 25 kV OCS, the rated insulation voltage is given as 27.5 kV in Table D.1 and, for fixed installations, the rated impulse voltage is given as either 170 kV or 200 kV for the OV3 and OV4 overvoltage categories respectively. The designer shall determine the category applicable to the OCS and shall furnish justification for the selection. Pollution categories and associated creepage distances are also covered in EN 50124-1, and insulation for the system shall be designed accordingly.

21.14 OCS Clearances and Protection against Electric Shock

Protection against electric shock can be achieved by establishing adequate safety clearances that minimize the possibility of direct contact by persons with energized parts, and/or by erecting suitable barriers or screens to prevent direct contact, and installing appropriate signs warning of the potential dangers.

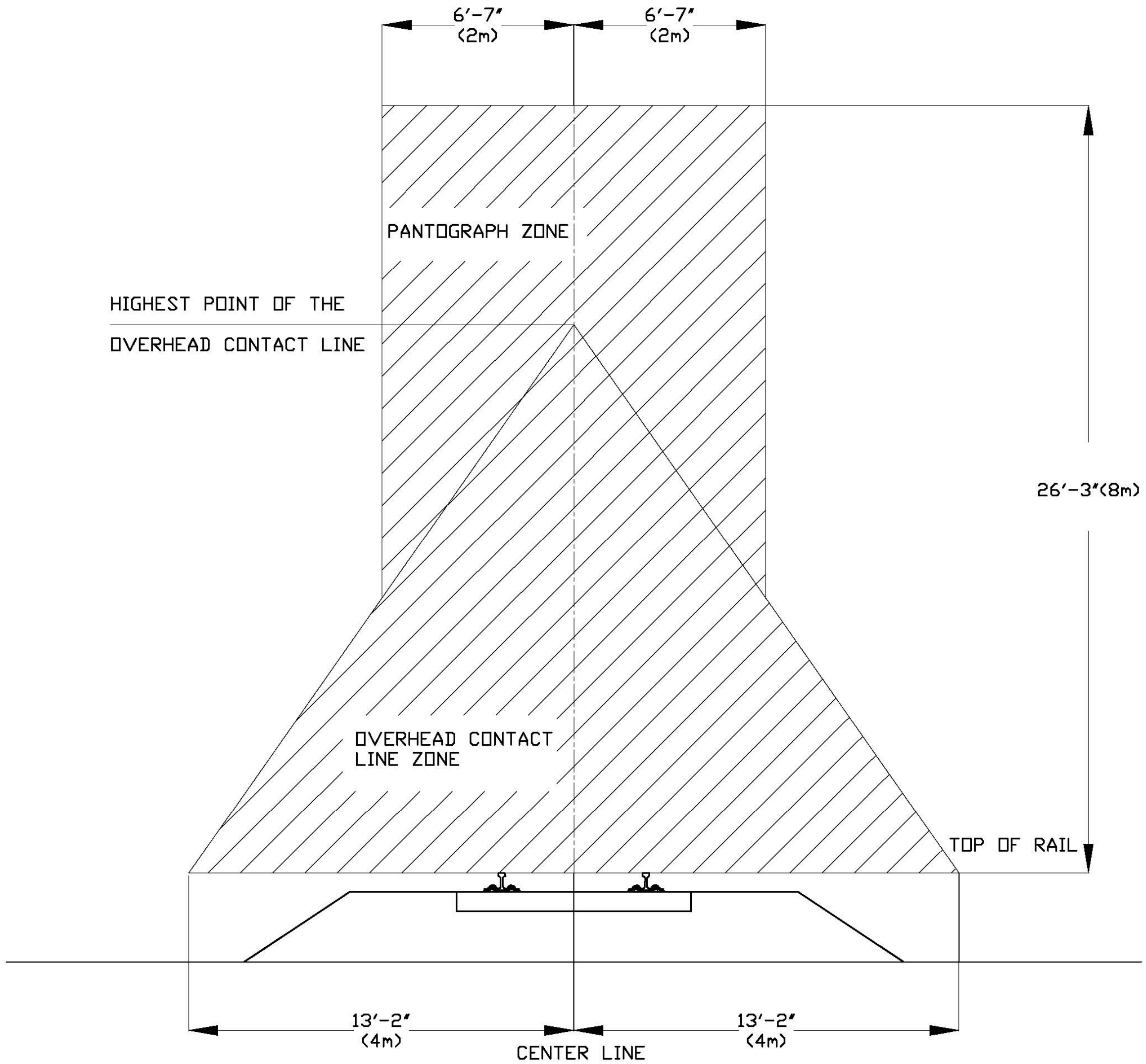
21.14.1 Overhead Contact Line Zone and Pantograph Zone

Structures and equipment may accidentally come into contact with a live broken contact line, or with the live parts of a broken or de-wired pantograph or energized fragments. Figure 21-5 has been derived from EN 50122-1: 1997 Figure 1 and defines the zone inside which such contact is considered probable but which limits are unlikely to be exceeded by a broken overhead contact line or damaged energized pantograph, or energized fragments thereof.

Note: The damaged pantograph may be live, even though it is not in contact with the overhead line, because it is inter-connected with other energized pantographs or because the train is in regenerative braking mode.

The limits of the overhead contact line zone below top of rail extend vertically down to the earth surface, except where the tracks are located on an aerial structure where they extend down to the deck of the aerial structure. In the case of out of running OCS conductors, the overhead contact line zone shall be extended accordingly.

Figure 21-5: Overhead Contact Line Zone and Pantograph Zone



Source: Derived from EN 50122-1: 1997 Figure 1

21.14.2 Protection by Clearances from Standing Surfaces

The minimum unconstrained clearances from energized parts to generally accessible areas (no barriers, screens or other physical restrictions to movement) for 25 kV systems have been derived from EN 50122-1: 1998 Figure 14 and values are depicted in Figure 21-6 for both public areas and restricted areas. The values shown are based on touching in a straight line without the use of tools or other objects and shall be achieved under all climatic and loading conditions. These requirements apply to clearances from standing surfaces used by people to accessible live parts on the outside of vehicles as well as to live parts of the OCS.

Placing energized parts over walkways shall be avoided wherever practical.

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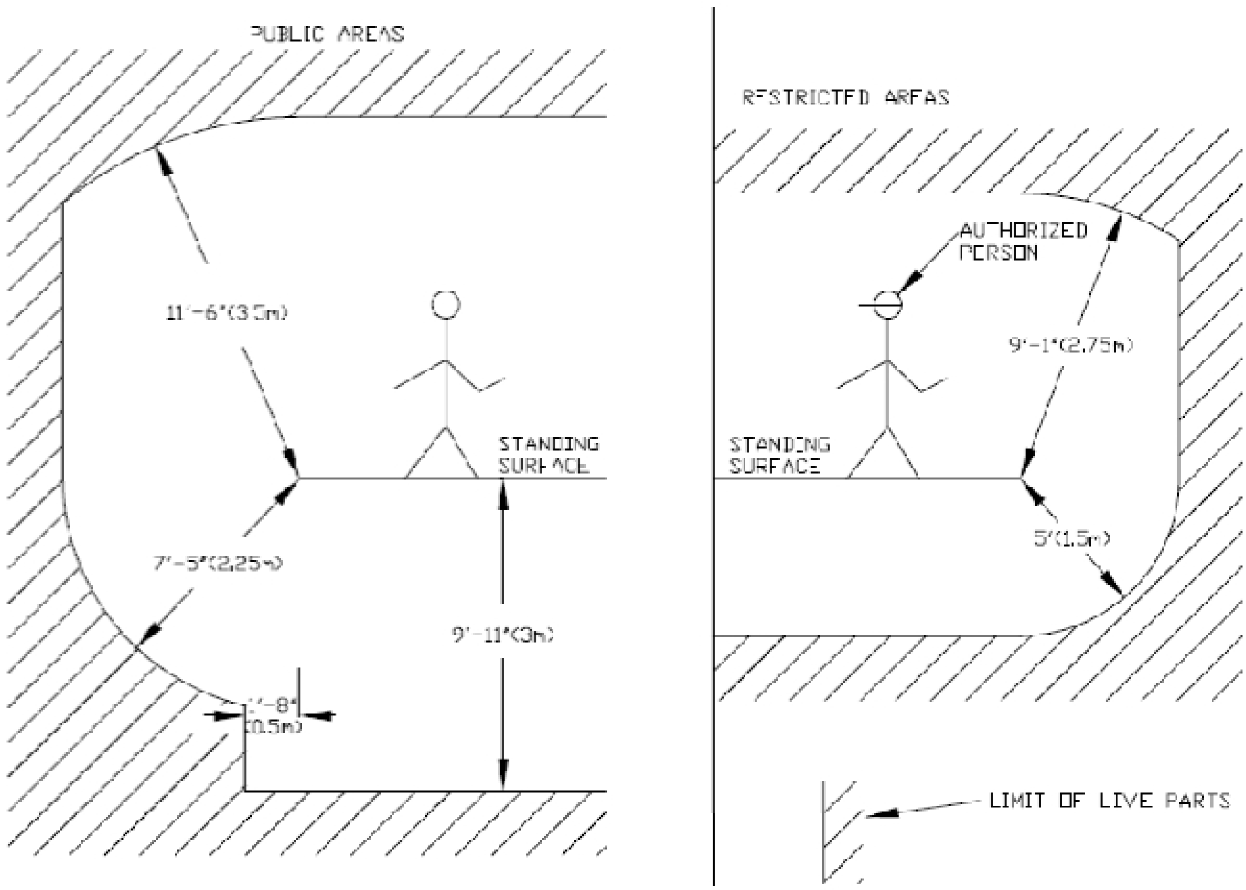
Safe working clearances and approach distances for qualified employees shall be developed by the applicable Agency for inclusion in the Safety Manual and appropriate work practices and procedures documents.

Figure 21-6: Minimum Required Safety Clearances – Unconstrained Access



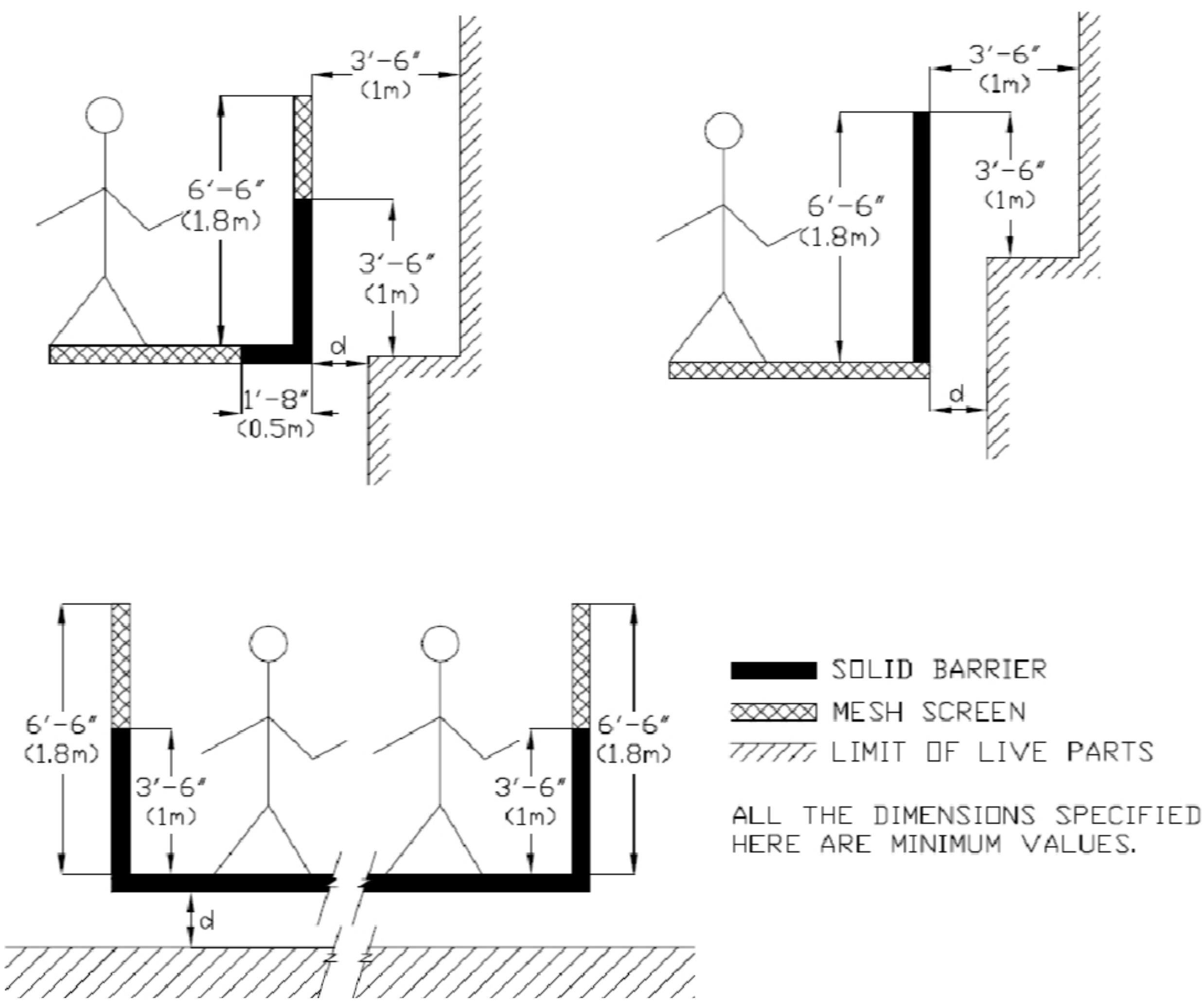
21.14.3 Protective Screening and Barriers for Standing Surfaces in Public Areas

The requirements for protective screening and barriers for use in public areas for protection against direct contact with adjacent live parts on the outside of vehicles or adjacent live parts of an overhead contact line system for normal voltages up to 25 kV ac to ground, where clearances are less than those shown in Figure 21-6, have been derived from EN 50122-1: 1997 Figure 18 and are shown in Figure 21-7 and are summarized as follows:

- Where the energized parts are located below the standing surface, protection of the standing surface shall be by means of a solid barrier.
- The minimum height of the protective barrier – solid barrier or a combination of solid barrier plus mesh screen, as shown - shall be 6'- 6" (1980 mm).

- Protective barriers of greater height may be required in areas where vandalism is prevalent.
- The value of Dimension “d”’ between the protective screen or barrier and live parts shall be determined from Table 21-5. Where mesh screens are used, 4 inches (100 mm) shall be added to the value of Dimension “d” and where buckling or warping of solid barriers is likely, 1.25 inches (30 mm) shall be added, in accordance with EN 50122-1 Clause 5.1.3.1.2.
- The length of the protective screening and/or barrier on structures that cross over the electrified railroad, which protect publicly accessible standing surfaces, shall be extended laterally beyond the live parts of the overhead contact line by at least 10 feet (3.05 m) on each side. In the case of energized conductors not being used for current collection (e.g., line feeders, reinforcing feeders, out of running overhead contact lines), the barrier shall extend for a width of at least 10 feet (3.05 m) on each side of the conductor, with the proviso that movements due to dynamic and thermal effects shall be taken into account.

Figure 21-7: Clearances from Protective Screens and Barriers for Standing Surfaces in Public Areas



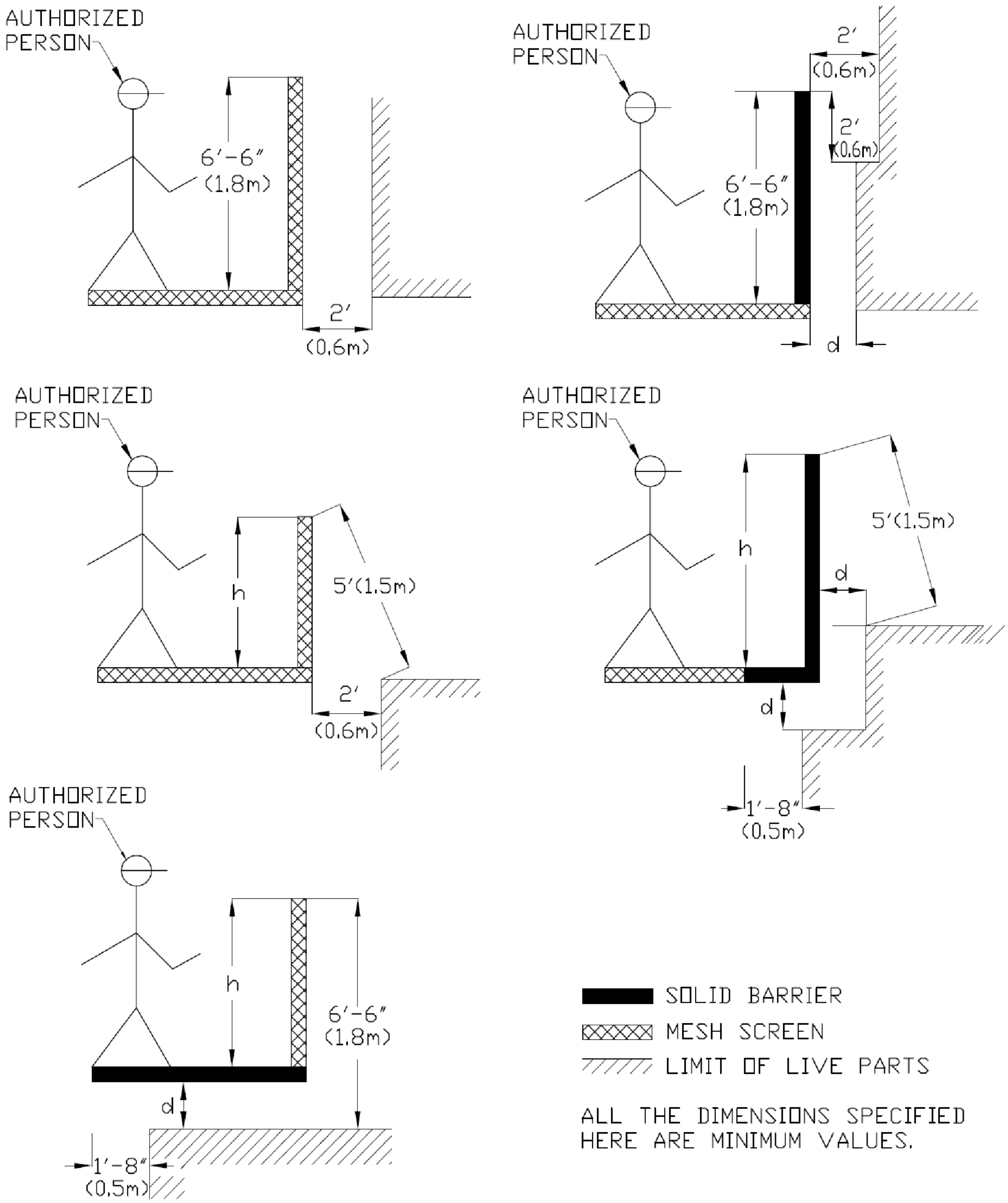
Source: Derived from EN 50122-1: 1997 Figure 18

21.14.4 Protective Screening and Barriers for Standing Surfaces in Restricted Areas

The requirements for clearances from protective screening and barriers for standing surfaces in restricted areas for protection against direct contact with adjacent live parts on the outside of vehicles or adjacent live parts of an overhead contact line system for normal voltages up to 25 kV ac to ground, where clearances are less than those shown in Figure 21-6, have been derived from EN 50122-1: 1997 Figure 16 and 17, and are shown in Figure 21-8 and are summarized as follows:

- For standing surfaces above live parts on the outside of vehicles or above live parts of an overhead contact line system, the protection shall be of solid barrier construction.
- The length of the solid barrier, protecting the standing surface, shall correspond to the pantograph zone and shall extend beyond the live parts of an overhead contact line by at least 1 foot 8 inches (510 mm). In the case of energized conductors not being used for current collection (e.g., line feeders, reinforcing feeders, out of running overhead contact lines), the barrier shall extend for a width of at least 1 foot 8 inches (510 mm) on each side of the conductor, with the proviso that movements due to dynamic and thermal effects shall be taken into account.
- The height “h” of the protective screening and barrier shall be such that a clearance of 5 feet (1525 mm) from the top of the protective screening and barrier shall be maintained (see Figure 21-8).
- The height of the side protective screenings and barriers shall correspond to the height of the required safety railing but should be a minimum of 3 feet 6 inches (1070 mm).
- The value of Dimension “d”’ between the protective screen or barrier and live parts shall be determined from Table 21-5. Where mesh screens are used, 4 inches (100 mm) shall be added to the value of Dimension “d” and where buckling or warping of solid barriers is likely, 1.25 inches (30 mm) shall be added, in accordance with EN 50122-1: 1998 Clause 5.1.3.1.2.

Figure 21-8: Clearances from Protective Screenings and Barriers for Standing Surfaces in Restricted Areas



Source: EN 50122-1 Figure 16 and 17

21.14.5 Additional Requirements for Protection Barriers and Screens

Protection barriers or screens shall be of sufficient strength and shall be supported rigidly and securely enough to prevent them from being displaced or dangerously deflected by a person slipping or falling against them.

Barriers and screens shall be permanently fixed, and shall be removable only with tools. Barriers in public areas shall employ non-removable, captive fasteners.

Barriers shall be of solid construction and fabricated from either conductive or non-conductive materials.

- Non-conductive barriers shall be surrounded by a grounded, bare conductor that is inter-connected with the traction system ground, preferably at not less than two locations.
- Conductive barriers shall be bonded and grounded by inter-connection with the traction system ground, preferably at not less than two locations.

Screens shall be of grounded, conductive, open mesh materials, and shall be grounded by inter-connection with the traction system ground, preferably at not less than two locations. Non-conductive mesh or plastic-coated metal mesh shall NOT be used.

Conductive mesh screens shall be constructed such that a cylinder, greater than ½ inch (13 mm) in diameter, cannot be pushed through the mesh. Mesh screen construction shall be such that required clearances to energized parts are maintained.

The style of barrier to be employed is dependent upon type of standing surface and its proximity to the energized parts, and whether the surface provides for public or restricted access, as detailed above.

The size of the barrier or screen shall be such that energized parts cannot be touched in a straight line by persons on a standing surface.

The design of the protective screens and barriers shall minimize the loading on the existing structures and the adverse visual impact.

The metallic parts of overhead bridge screens and barriers shall be bonded to the static wires. Other metallic items under overhead bridges, within a lateral distance of 10 feet (3.05 m) of any energized and uninsulated equipment below the structure, shall be directly or indirectly bonded to the static wires.

21.14.6 Protection Against Climbing

Where there is public access or trespass is likely, anti-climbing protection shall be provided at buildings and other structures supporting energized parts of the OCS. The anti-climbing protection shall include signs warning of the dangers of high voltage.

Access to fixed ladders, particularly at signal poles and signal gantries, and the means of access to any roof or other place, which could allow non-authorized persons to approach energized parts, shall be secured or otherwise protected.

21.14.7 Clearances for Utility Lines Crossing over the Electrified Railroad

The minimum clearance for overhead power, communications or other utility lines, which are not part of the Traction Electrification System (TES), shall be in accordance with CPUC General Order No. 95 Rule 38 Table 2 and shall be measured from the highest energized point on the TES.

For any crossing of the high-speed lines, the utility shall comply with the requirements of CPUC General Order No. 95 with regard to the conductor suspension arrangements and strength of the structures immediately adjacent to the crossing point.

21.14.8 Electrical Clearances to Rail Vehicles and Structures

Clearances are classified as either Static or Passing.

Static Clearance is the physical air clearance between energized parts of a vehicle or OCS when not subjected to dynamic conditions or climatic influences or pantograph pressure, and an adjacent fixed structure or the grounded parts of a vehicle, while the vehicle is stationary.

Passing (or Dynamic) Clearance occurs under dynamic operating conditions that exist during the passage of a train, or when the OCS is affected by extreme climatic conditions, such as wind and/or ice loading. Passing (or Dynamic) Clearance is the physical air clearance between energized parts of either the vehicle or OCS and the grounded vehicle, or between energized parts of either the vehicle or OCS and an adjacent fixed structure.

Electrical clearances, shown in Table 21-5 and depicted in Figure 21-9, from energized parts to grounded parts of rail vehicles or structures are categorized as Normal and Minimum and are applicable, as noted, in Non-Polluted and Polluted atmospheric locations. Typical polluted conditions are detailed in Section 21.5.4 and the designer shall determine their applicability. Polluted locations/areas shall be so noted in the designs, so all users are aware that increased clearances must be employed and maintained. Where the OCS is to be installed at elevations greater than 3,000 feet (900 m), the clearances shall be increased in accordance with the Altitude Correction Factors (A) given in Table 21-6. Elevated locations and the consequent increased clearance requirements shall be clearly indicated in the designs.

Table 21-5: 25 kV ac Electrical Clearances

Atmospheric Condition	Normal Clearance		Minimum Clearance	
	Static (C_A)	Passing/ Dynamic (P_A)	Static (C_A)	Passing/ Dynamic (P_A)
Non-Polluted	10.5 inches (270 mm) *	8 inches (205 mm) *	8 inches (205 mm) *	6 inches (155 mm) *
Polluted	12.5 inches (320 mm) **	10 inches (255 mm) **	10 inches (255 mm) **	8 inches (205 mm) **

* These clearance values are as stated in AREMA Table 33-2-4 (2010)

** For polluted atmospheres, 2 inches has been added as stated in AREMA Table 33-2-4 (2010)

The designated normal clearances shall be adopted at all locations, wherever practicable. Where it can be demonstrated that it is not practicable to provide normal clearances, adoption of the minimum clearances shall be permissible. However, prior to their adoption, the following factors shall be further evaluated:

- Fault current resulting from a breakdown of the electrical clearance.
- Vulnerability of the OCS and railroad infrastructure to damage should a breakdown of the electrical clearance occur.
- Consequences for the safety of persons should a breakdown of the electrical clearance occur.
- Application and maintenance of tolerances of the OCS and railroad infrastructure.
- Economic and technical considerations.

The minimum clearance from bare energized ancillary conductors (the 25 kV negative feeders) to grounded structures under worst case conditions in non-polluted areas is specified in the AREMA Manual Chapter 33 Table 33-2-2 to be 10.5 inches (270 mm) and 12.5 inches (320 mm) in polluted locations. These values shall be adopted for the project.

In a 2x25 kV ac system, there is a 180^o phase difference between parts common to the energized negative feeder and parts common to the energized catenary system. The minimum clearance between these elements shall be as stipulated in Table 10 of EN 50119: 2001, which is 21.5 inches (540 mm) under static conditions or 12 inches (305 mm) under worst case dynamic conditions.

Note: In accordance with NESC Rule 441A4b(3), altitude correction factors ($_A$) shall be applied to clearances when the worksite location is above 3,000 feet (900 m). The factors are detailed in NESC Table 441-5 and shown below in Table 21-6.

Table 21-6: Altitude Correction Factors ($_A$) to be Applied to Clearances

Altitude (ft)	Altitude (m)	Correction Factor
3,000	900	1.00
4,000	1,200	1.02
5,000	1,500	1.05
6,000	1,800	1.08
7,000	2,100	1.11
8,000	2,400	1.14
9,000	2,700	1.17
10,000	3,000	1.20

Enhanced clearances or other protective measures shall be provided at locations where there is a high probability of incidents due to birds, animals, icicles or vandalism, or for particularly vulnerable structures. The maximum practicable value of electrical clearance shall be provided at all locations.

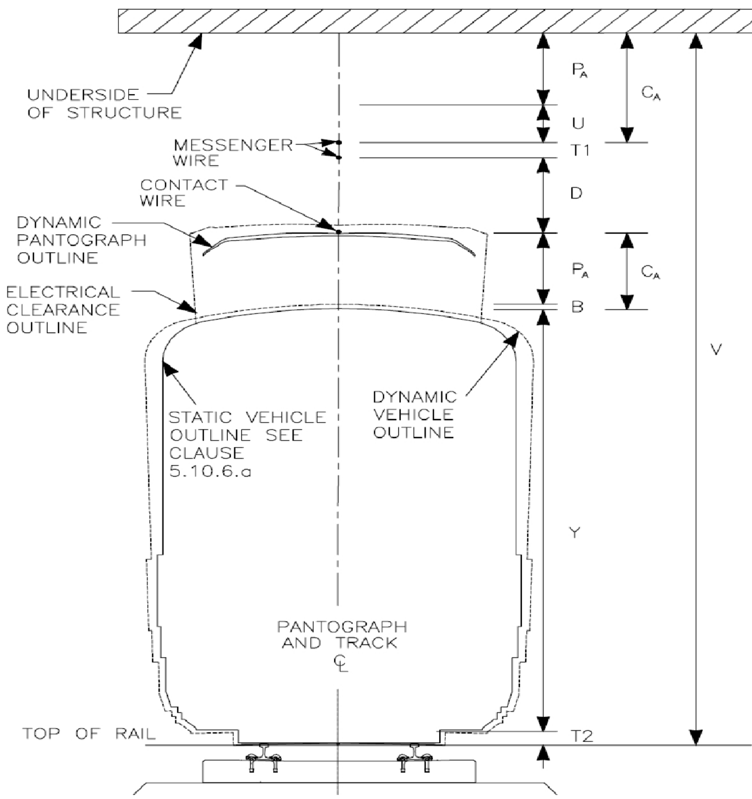
21.14.9 Clearance Envelope at Fixed Structures

In determining the minimum vertical clearance envelope at fixed structures, including OCS support structures and signal bridges, the following factors shall be assessed, as shown in Figure 21-9:

- The static vehicle outline, which shall be based on the size of the high-speed rail vehicles.
- The dynamic vehicle outline, which shall take into consideration the dynamic swept envelope, track position and maintenance tolerances, including railhead side wear, and the effects of vertical and horizontal curvature, including track super-elevation. Refer to the *Trackway Clearances* chapter for further information regarding vehicle clearance requirements.
- The position of energized parts on the rail vehicles, including the dynamic pantograph envelope, allowing for pantograph carbon wear and dynamic movements and deflections of the pantograph frame, and vehicle construction and maintenance tolerances. The pantograph envelope shall include an allowance for chording effects, if the pantograph is offset longitudinally on the vehicle from a truck centerline.
- The position and size of energized parts of the OCS allowing for installation and maintenance tolerances, uplift and other dynamic movements, including those due to wind, temperature and loading conditions.
- Electrical clearance values as applicable for non-polluted or polluted areas.
- For minimum vertical clearances for new and existing structures, refer to the *Trackway Clearances* chapter.

- In assessing the minimum vertical clearance of the overhead structure, the vertical clearance between the energized bare negative feeder cable shall also be considered.

Figure 21-9: Vertical Clearance Envelope at Fixed Structures



Source: AREMA Figure 33-2-3 and Figure 33-2-4

V	=	Total Vertical Clearance Required for Electrification
P_A	=	Passing (Dynamic) Electrical Clearance – see Note below
U	=	OCS Uplift
T1	=	OCS Construction Tolerance
D	=	OCS Depth
B	=	Vehicle Bounce
Y	=	Static Vehicle Load Height
T2	=	Track Maintenance Tolerance
C_A	=	Static Electrical Clearance

Notes: The diagram depicts the dynamic condition. For static situations, the Static Electrical Clearance (C_A) – refer to Table 21-5 - shall be not less than P_A+U or P_A+B

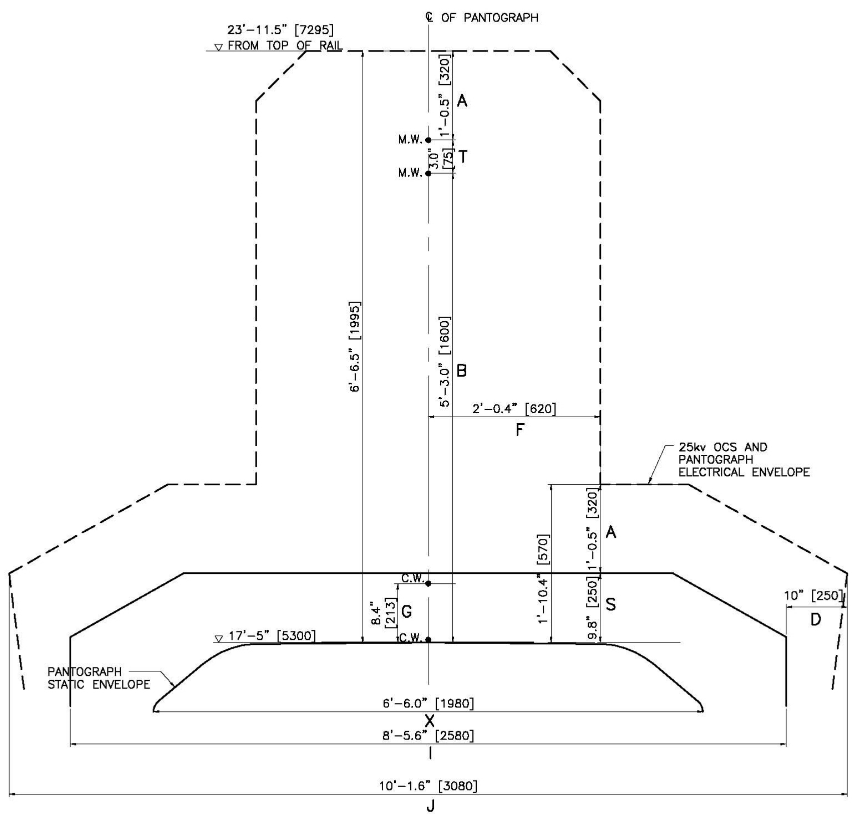
($_A$) - At higher elevations, Static and Passing Electrical Clearances shall be adjusted using the appropriate Altitude Correction Factor derived from Table 21-6.

The minimum lateral clearance at fixed structures, including OCS poles and other OCS support structures and signal bridges, shall comply with the clearance requirements detailed in the *Trackway Clearances* chapter.

21.14.10 Applicable Pantograph and OCS Clearance Envelopes

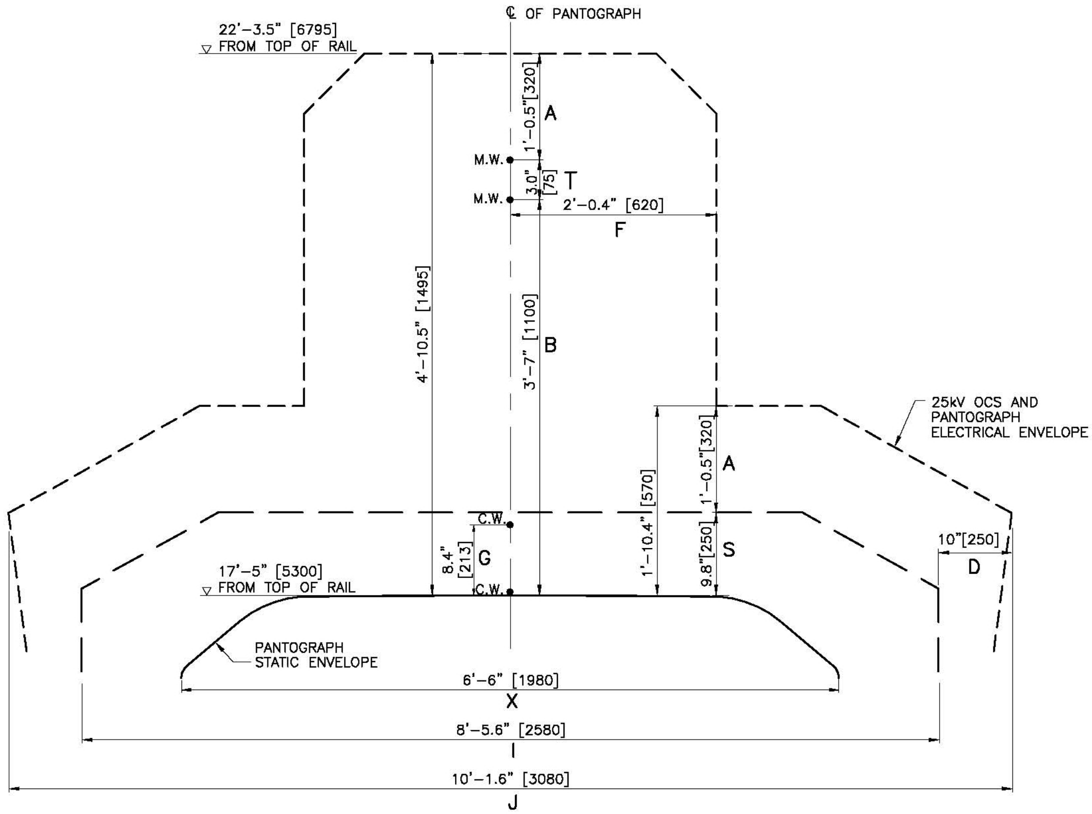
In assessing clearances along the alignment to accommodate the OCS and Pantograph, the following two Clearance Envelopes, which incorporate electrical clearances somewhat greater than the polluted area clearances quoted in Table 21-5, shall be adopted. For non-polluted areas, the diagrams can be reduced in size by incorporating the non-polluted electrical clearance values indicated in Table 21-5.

Figure 21-10: OCS and Pantograph Clearance Envelope for 220 mph (352 km/hr) High-Speed Operations in Polluted Areas – Open Route



A	=	Static Electrical Clearance
D	=	Passing Electrical Clearance
B	=	System Depth 5 feet 3 inches (1600 mm) for dedicated high-speed lines
F	=	Wire Deflection (maximum deflection of the contact wire under dynamic conditions as indicated in Section 21.6.2) + D (Passing Electrical Clearance)
G	=	5.9 inches (150 mm) Wire Uplift and Hardware Dimension + 2.5 inches (63 mm) Track and OCS Tolerances
X	=	Combined Pantograph - Maximum Static Envelope (see Figure 21-1)
I	=	Total Width of Dynamic Pantograph Envelope (= 2xL2) where L2 is derived from the formula given EN 50367: 2006 Annex A.3
J	=	Total Width of Electrical Envelope (= I + 2xD)
S	=	Design-basis Pantograph Uplift for clearance purpose (= 2xSo see Section 21.10.5)
T	=	Messenger wire tolerance (larger tolerance of construction and maintenance tolerances)

Figure 21-11: OCS and Pantograph Clearance Envelope for 220 mph (352 km/hr) High Speed Operations in Polluted Areas – Tunnels



A	=	Static Electrical Clearance
D	=	Passing Electrical Clearance
B	=	System Depth 3 feet 7 inches (1093 mm) for tunnels
F	=	Wire Deflection (maximum deflection of the contact wire under dynamic conditions as indicated in Section 21.6.2) + d (Passing Electrical Clearance)
G	=	2 inches (50 mm) of Uplift + 2.5 inches (63 mm) of Track and OCS Tolerances
X	=	Combined Pantograph - Maximum Static Envelope (see Figure 21-1)
I	=	Total Width of Dynamic Pantograph Envelope per AREMA 2009 Manual Chapter 33 Formula 2.2.8.2 (= 2xSs + X + E + 2xL where Ss is the vehicle sway, E is the lateral allowance for track superelevation, and L is the allowance for lateral track shift)
J	=	Total Width of Electrical Envelope (= i + 2xd)
S	=	Design-basis Pantograph Uplift for clearance purpose (see Section 21.10.5)
T	=	Messenger wire tolerance (larger tolerance of construction and maintenance tolerances)

21.15 OCS Structural Requirements

21.15.1 General

In the above grade sections, the OCS poles shall be either galvanized H-section wide flange beams or galvanized round, tapered tubular steel sections. In residential areas and at passenger stations round, tapered tubular steel poles shall be used. All poles shall be of the bolted base type and shall be designed and manufactured to relevant U.S. steel standards.

Where multiple OCS equipments are to be supported in the above grade sections, such as at overlaps and turnouts, multiple cantilevers may be attached to a single structure, which shall be of a heavier section such that the applied loads shall not cause twisting of the structure by more than 5 degrees.

For multi-track areas where independent poles cannot be installed between tracks, portal structures with bolted base support poles and with drop tubes to support the OCS equipment related to individual tracks shall be used, thereby providing for mechanical independence of the individual equipments.

In general, OCS poles in station areas shall be located between tracks. For situations where OCS poles must be located on station platforms, they shall be placed in a manner that minimizes the visual impact and obstruction to passengers, and shall be integrated with platform architecture design. The minimum distance from platform edge to face of poles shall be 7 feet. Counterpoise grounding shall be used within passenger stations, and the aerial static wire shall be electrically isolated from the OCS structures and components connected thereto.

Wall brackets and drop pipe supports in tunnels and cut-and-cover box structures shall be of galvanized steel, and shall be attached using either C-channels or anchor expansion bolts of the undercut type. Where bracket installation requires drilling of reinforced concrete, the specifications shall require that specialized equipment be used to locate the reinforcing bars before drilling commences. The minimum distance from a reinforcing bar to a drilled hole shall be 2 inches (50 mm).

For OCS poles on aerial structures, refer to the *Structures* chapter and Standard and Directive Drawings for the embedded anchor bolt sleeve detail.

21.15.2 OCS Pole and Foundation Requirements

The pole and foundation locations shall be designed in a manner that avoids conflicts with existing or planned overhead or underground obstructions. For existing revenue service locations, the foundation shall be constructed in a manner that does not disturb the existing tracks under revenue service.

The loading assumptions and strength requirements shall meet or exceed the requirements of NESC rules. The general design loads include dead load, live loads - wind and ice, and

earthquake load. However, as noted in NESC Rule 250A4, the structural capacity provided by meeting the loading and strength requirements of NESC Section 25 and 26 will provide sufficient capability to resist earthquake ground motions.

In addition to the load conditions indicated in NESC, a 100 mph (44.7 m/s) wind plus 10 percent gust allowance shall be evaluated to prove no failure. The designer shall also evaluate the local extreme climatic conditions and adjust the load combinations for worst case loads, including the effects of wind pressure on OCS poles due to slipstream effects per the *Structures* chapter.

All structures, poles, brackets, foundations and anchors shall be capable of handling construction loads imposed during erection and during catenary assembly and wire installation, and of withstanding a broken-wire failure, including breakage of both the static wire and parallel feeder conductor in any one span, without exhibiting major, catastrophic damage. These support structures shall also be capable of handling the loads due to breakage of other parts of the OCS. Pole and foundation loadings and structural designs shall be developed in accordance with the criteria defined herein. To facilitate aerial structure design, maximum loads for design of OCS pole foundation on aerial structures are specified in the *Structures* chapter.

All steel materials, related processes and manufacturing methods shall be specified in accordance with ASTM standards, wherever applicable and deemed appropriate, including requirements for hot-dip galvanizing of steelwork and hardware.

The design of bolted steelwork connections shall conform to AISC requirements and shall specify materials and methods in accordance with ASTM standards.

Anchor bolts (hold-down bolts) shall be galvanized.

OCS foundations and structures shall be designed so that their deflection under the loads imposed during normal operating conditions shall not cause a contact wire displacement that could prejudice acceptable tracking and performance of the pantograph current collector. To this end, the maximum allowable live-load operating deflection of the pole and foundation structure together shall be limited to 2 inches (50 mm) at the normal design contact wire height. For the purposes of structural design, this live loading shall be considered a dynamic operating condition, and the structure shall fully recover from its displacement due to the live loading.

For all non-operating loading conditions, excluding seismic conditions, the maximum total deflection of the pole and foundation together (measured at the pole top) shall not exceed 2.5 percent of the total pole length due to both static (dead) loads and live loads combined.

The foundation and steel pole, or vertical members of the support structure, shall be designed to enable the pole to be raked during installation. This rake shall allow for the static dead loads that are imposed on the structure by the cantilevers, equipment and along-track conductors. Rake installation shall provide for a visually plumb and vertical pole after application of the full static loading. This position shall serve as the design reference datum for the calculation of the

live-load operating deflection. All OCS alignment and wire layout designs shall utilize this static, plumb, dead load position as the true pole-face reference datum.

The OCS foundations and poles shall be designed in a manner to minimize the number of types and sizes to simplify constructability, to avoid disturbing existing adjacent structures, to provide flexibility for pole rake adjustment, and to minimize future maintenance inventory and costs.

Anchor bolt patterns shall be selected to provide coordinated relationships between poles and foundations. The coordination shall be based on matching strengths and minimizing the number of required configurations.

Particular attention shall be given to the provision of a high level of protection against atmospheric pollution and contamination to maintain the design life without frequent maintenance cycles.

OCS support locations shall be individually numbered for ease of identification on site. Structure number plates shall be fitted to the structure at a height of 6 feet 6 inches (1.98 m) approximately above rail level. For supports located in tunnels, the number plate shall be attached to the wall using suitable fixings.

21.15.3 OCS Poles

Poles shall be designed as free-standing structures, except for poles carrying wire terminations, which shall be down-guyed, typically in the along track direction. The lateral offset from centerline of tangent track to centerline of pole shall be 10 feet-8 inches. Offsets shall be increased as needed to satisfy curved track situations and/or signal sighting requirements.

Aerial structures will be designed in a manner such that OCS poles can be located at any position along the structure. Alternatively, working in close coordination with the OCS designer, aerial structures can be designed to provide site-specific locations for OCS pole installations.

The OCS supporting structures shall be calculated in accordance with relevant American standards (ACI, AISC, ANSI, ASCE, NESC). The allowance for a one-third increase in allowable stress for wind combined loading shall be waived.

The design of structural and fabrication welding shall conform to the AWS, Standard D.1.1, “Structural Welding Code”.

Painted poles shall not be precluded from use in passenger stations, within any urban design area, or in other special circumstances. Painting shall be specified to conform to the Steel Structure Painting Council, “Steel Structure Painting Manual,” Volumes 1 and 2.

21.15.4 OCS Foundations

The OCS foundations shall be capable of meeting the structural loading requirements, and shall be designed for each individual location. The structural dimensions will be dependent on:

- Loads on the poles due to the OCS conductors, feeder cables, tensioning equipment, insulators, mid-point anchor ties, and all other necessary equipment.
- Wind loads on the poles and associated OCS conductors and equipment.
- Soil conditions.
- Earthquake loads.
- Operational requirements the applicable speed.

OCS foundation designs shall be in accordance with ACI, AISC, and ASTM standards, other applicable codes, and proven foundation engineering and anchoring methods. Foundation designs shall consider buoyancy effects where applicable.

Augered, cast-in-place concrete foundations with a nominal diameter of 3 feet shall be adopted for all normal situations. Site-specific conditions or unusual loading combinations may dictate the adoption of other types or sizes of foundations. The permissible increase in soil resistance values, as defined in the CBC as being applicable to free-standing structures, shall be taken into consideration in the design of OCS foundations, in accordance with the CBC formulae.

The OCS foundations shall be designed to exceed the maximum design capability of the pole or structure being supported by the foundation by not less than 25 percent to ensure the foundation will not experience failure under the specified operating and non-operating conditions. The overturning moment shall not exceed 85 percent of the stability moment.

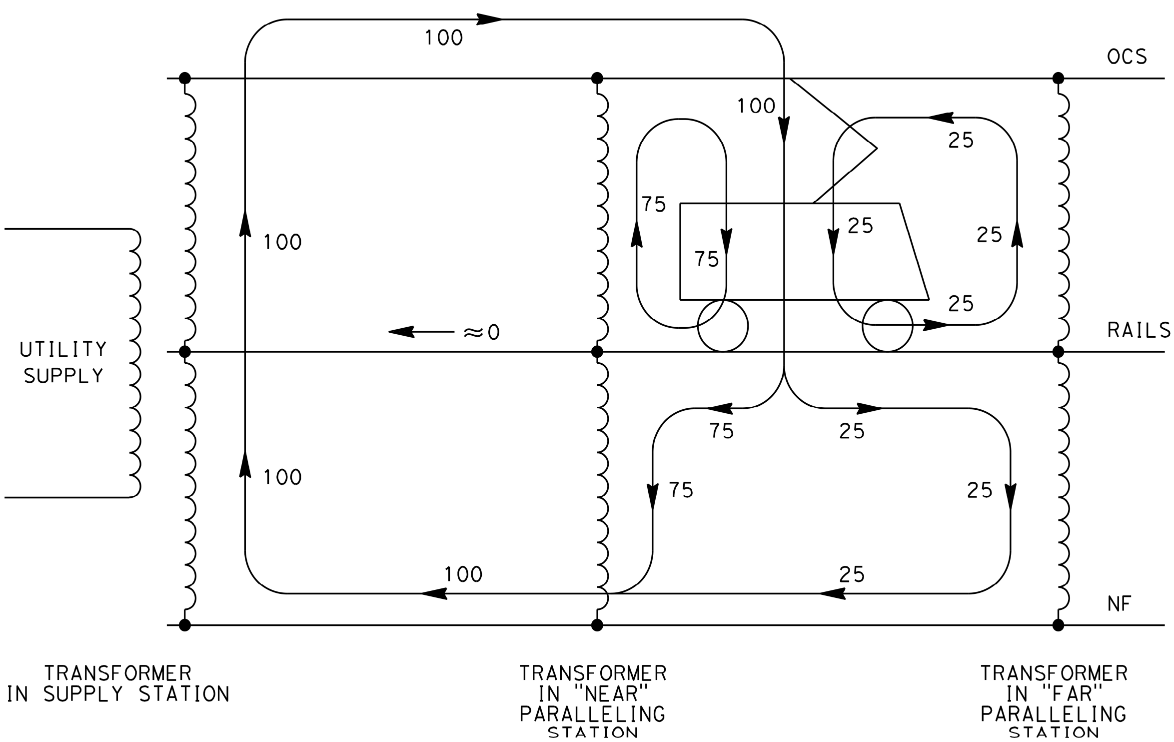
Where fragmented rock is encountered, excavation shall be required for the installation of standard foundations. Where solid rock is encountered below grade (i.e., with soil cover), epoxy-grouted dowels shall be anchored to the rock, and the upper portion of a standard anchor-bolt foundation cast into the soil. Where solid rock is encountered at-grade (no soil cover), the anchor bolts shall be epoxy-grouted into the rock (with appropriate pull-out tests being performed) and with a small foundation-top cast around the bolts, primarily for aesthetic effect.

21.16 Traction Power Return System

The Rail Return System comprise the running rails, impedance bonds, static or ground wires, return cables, and the earth, each of which provides a part of the electrically continuous return path for the traction currents (refer to Figure 21-12). The Rail Return System together with the Parallel Negative Feeders comprise the Traction Power Return System, through which the whole traction current is returned from the wheel sets of the traction units to the substations.

The whole traction return current of a train operating between any two adjacent autotransformers flows through the rail return system within the bounds of these two autotransformers. These autotransformers, however, “force” a major portion of the traction return current to flow into the negative feeders, thereby minimizing the flow of return current in the rails in sections away from the train operating section. This is a safety related benefit of the autotransformer feed system, the other benefit being reduced electro-magnetic interference produced in this system as compared to the direct feed system.

Figure 21-12: Typical Proportional Current Distribution in a 2x25 kV Autotransformer System for a Train Current of 200 Amps



It is recognized that Figure 21-12 is a simplified diagram and is not an accurate representation of all current flows, since portions of the return current flow from the train location back to the substation via the static wires and earth. Further, a portion also remains in the track rails.

21.17 OCS Interfaces with Other Disciplines

To achieve satisfactory performance of the OCS and current collection by the electrically-powered HSR vehicles, it is essential that the OCS designer work closely with other disciplines. The following is not a totally inclusive listing, but provides guidance to the OCS designer and indicates some of the major issues that must be addressed during the final design process:

21.17.1 Traction Power Supply System

- Confirmation of OCS and ancillary conductor sizes based on the traction power load flow studies.
- Confirmation of insulated cable sizes for both aerial and underground applications based on the load flow studies.
- Confirmation of traction power facility locations, and particularly of the SS and SWS where phase breaks are required.
- Recommended frequency of static wire to rail connections based on the rail potential rise calculations.
- Confirmation of proposed OCS sectionalizing scheme based on coordination with Operations and Maintenance requirements.

21.17.2 Rolling Stock

- Confirmation of the selected vehicle and pantograph operating characteristics for input into the OCS-Pantograph dynamic simulation program analyses.
- Confirmation of pantograph spacing, on train consists using multiple pantographs, for input into the OCS-Pantograph dynamic simulation program analyses and for development of OCS phase break designs.

21.17.3 Train Control System

- Coordinate locations of impedance bonds.
- Coordinate signal sighting requirements.
- Coordinate wayside power cubicle requirements and locations.

21.17.4 Communications System

- Coordinate wayside power cubicle requirements and locations.
- Coordinate OCS disconnect switch RTU (Remote Terminal Unit) and interface requirements.

21.17.5 Aerial Structure Design

- Coordinate location of OCS poles and pole loadings.

21.17.6 Trackwork

- Coordinate locations of impedance bonds.
- Confirm space requirements below rails for the installation of return cables and connections to impedance bonds.

Chapter 22

Grounding and Bonding Requirements

HSR 13-06 - EXECUTION VERSION

Revision	Date	Description
0	02 Mar 12	Initial Release, R0
0.1	Dec 2012	EXECUTION VERSION

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Acronyms

ac	Alternating Current
ATC	Automatic Train Control
CIC	Communications Interface Cabinet
EMI	Electromagnetic Interference
IEC	International Electrotechnical Commission
MOI	Maintenance of Infrastructure
O&M	Operations and Maintenance
OCS	Overhead Contact System
OSP	Outside Plant Cable
RGB	Rack Grounding Busbar
SRG	Signal Reference Grid
STP	Single Twisted-Pair
TBB	Telecommunications Bonding Backbone
TBBIBC	Telecommunications Bonding Backbone Interconnecting Bonding Conductor
TGB	Telecommunications Grounding Busbar
TES	Traction Electrification System
TPF	Traction Power Facility
UL	Underwriters Laboratories, Inc.
WPC	Wayside Power Cubicles

22 Grounding and Bonding Requirements

22.1 Scope

Grounding, Bonding, and Lightning Protection shall be designed to address three purposes: (1) personal safety; (2) equipment, cabling and building protection; and, (3) equipment noise reduction. This chapter addresses the first two items, and equipment noise reduction is addressed in the *Electromagnetic Compatibility and Interference* chapter. Grounding and bonding design shall be compatible with the requirements of the *Electromagnetic Compatibility and Interference* chapter.

This chapter also provides criteria for the electrical separation of outside utility lines from the traction return and grounding systems.

Grounding is the establishment of a common reference voltage (typically 0 V) between power sources and/or electrical equipment. Electrical ground faults, short circuits, lightning, and transients can occur in electrical power supply and distribution systems or the facilities power systems. These design criteria specify requirements for the protective provisions relating to electrical safety in structures associated with the alternating current (ac) traction system and to any structures that may be endangered by the traction power supply and distribution systems or the facilities power system, and to any automatic train control (ATC), communications, or other electronic equipment that must be protected from electrical shocks. The grounding of ATC, communications, and other electronic equipment sensitive to high currents and/or voltages is also covered in this chapter. Grounding systems are intended to help clear faults in the quickest possible manner by providing a low impedance path for fault currents.

Grounding, Bonding, and Lightning Protection is multi-disciplinary in nature. The design shall consider and mitigate the negative effects of lightning, ground potential rise, contact with electrical power circuits, and induction. The various discipline designers must collaborate with one another to coordinate the overall grounding and bonding design, so that a consistent approach is used and applied by each discipline in the development of the electrical, power and structural grounding and bonding and lightning protection. Refer to Standard and Directive Drawings for additional requirements.

Where multiple codes address the same issue, but specify differing approaches or values, the most stringent requirement shall be met.

In addition, this chapter provides criteria for designs that will minimize the touch voltage and ground return currents created by the electrification system and facilities electrical systems that will provide for the safety of passengers and operating personnel and minimize the hazards of electrical shock. The grounding and bonding system designs shall provide the means to carry electric currents into the earth under both normal and fault conditions without exceeding any operating and equipment limits or adversely affecting continuity of service.

For ac traction systems, grounding is the preferred method for reducing potentials of the electrical system both during normal operations and under fault conditions to protect equipment and to provide safety for employees and the general public. Adequate bonding shall be designed and installed throughout the entire electrified system to provide proper return circuits for the normal traction power currents and fault currents, with grounding connections as detailed in these criteria.

In principle, to assure the integrity of the grounding and bonding systems and the longevity of the system components, particularly for buried or encased elements, the bonding and grounding designs shall create duplicate electrical continuity paths and provide for redundancy in jumpers and bonds.

Design documents shall identify each type of ground connection, consistent with the ground categories identified in the *Electromagnetic Compatibility and Interference* chapter and as indicated in the following sections.

22.2 Regulations, Codes and Standards

- California Code of Regulations, Title 24 (California Building Standards Code which includes the California Electrical Code)
- California Public Utilities Commission (CPUC) General Order (GO) 95
- International Electrotechnical Commission (IEC) 60479: Effects of Current on Human Beings and Livestock – Part 1 General Aspects
- Institute of Electrical and Electronics Engineers (IEEE)
  - IEEE Std. 80: IEEE Guide for Safety in AC Substation Grounding
  - IEEE Std. 81: IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System (Part 1)
  - IEEE Std. 142: IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems (IEEE Green Book)
  - IEEE Std. C2: National Electrical Safety Code
  - IEEE Std. 1100: “Recommended Practice for Powering and Grounding Sensitive Electronic Equipment.”
  - IEEE Std. C62.41: “IEEE Recommended Practice for Surge Voltages in Low-Voltage AC Power Circuits”
- American National Standards Institute (ANSI): ANSI-TIA-EIA-607-A “Grounding and Bonding Requirements for Telecommunications in Commercial Buildings”
- National Fire Protection Association (NFPA)
  - NFPA 70: National Electrical Code

  - NFPA Std. 780: Standard for Installation of Lightning Protection Systems
- European Standards (EN)
  - EN 50119 - 2001: Railway Applications – Fixed Installations – Electric Traction Overhead Contact Lines
  - EN 50122-1 - 2011: Railway Applications – Fixed Installations - Part 1. Protective provisions relating to electrical safety and earthing
  - EN 50124-1 - 2001: Railway Applications – Insulation Coordination – Part 1. Basic requirements – Clearances and creepage distances for all electrical and electronic equipment
- The Manual for Railway Engineering of the American Railway Engineering and Maintenance of Way Association (AREMA Manual)
- Underwriters Laboratories (UL)
- U.S. Department of Defense (USDOD) Military Standards

22.3 General Grounding and Bonding Requirements

A uniform/standardized grounding and bonding system design shall be adopted to provide for protection of personnel and equipment. All grounding and bonding designs shall be coordinated with the various discipline designers, including civil, architectural, electrical and electronic, mechanical, plumbing and systems, such as traction power supply and distribution, communications, ATC, etc.. All grounding and bonding designs shall be coordinated with the stray current and corrosion control measures, and with the electromagnetic compatibility and interference requirements, so that the respective designs do not conflict and render other systems ineffective.

Non-current carrying conductive parts, such as conduit, cable trays, handrails, trackside fencing, etc. shall be electrically bonded to provide a continuous electrical path, and shall be permanently and effectively grounded. Grounding system designs may include the grounding of individual items, and/or dividing the length of non-current-carrying conductive entities into sections with each section grounded at only one point. Grounding and bonding conductor sizes shall be selected in accordance with the latest version of the applicable code. Ground resistance at each grounding location shall be less than or equal to the value specified in the applicable code.

An electrical safety analysis shall be undertaken to assess which metallic parts need to be grounded and bonded, and the appropriate methodology for implementation identified.

22.3.1 General Facility Grounding

The design of each large facility/building shall include a ground grid. Wayside houses shall be grounded by means of one or more interconnected ground rods. Where ground grids are used, the design shall adhere to the following requirements:

- Ground grid design shall be based on local soil resistivity and the calculations shall be in compliance with IEEE standards (e.g., 80, 142, and 1100) and the CEC/NEC/GO 95/NESC rules as applicable. Ground grids shall be constructed from an assembly of driven ground rods and bare copper conductors, installed adjacent to but not under the building, and shall achieve a ground resistance of not more than 5 ohms. A continuous loop of the grounding conductor(s) shall surround the perimeter of each facility/building, to which the perimeter fence and gates (where provided) shall be effectively bonded at frequent intervals, and within this loop the conductors should be laid in the form of a grid. At the cross-connections, the conductors should be securely bonded together by means of exothermic welds. Ground rods shall be installed at grid corners, at junction points along the perimeter, and at major equipment locations with the ground rods being driven vertically into the ground to not less than the minimum depth specified in NESC (2007) Rule 094B2a. Horizontal ground rod configurations may be required where subsurface rock or other obstructions interfere with the placement of vertical ground rods. The ground conductors may be made of copper or other metals/alloys that will not corrode excessively during the expected service life. Ground rods may be of zinc coated steel, stainless steel, copper-clad or stainless steel-clad steel. The ground conductors shall be securely bonded to the ground rods and to the equipment (including busbars) to be grounded. Joints shall be exothermically welded.
- The ground rods shall be driven to stable soil where constant conductivity properties apply.
- At least 2 ground test stations shall be provided at each ground grid.
- Ground test stations shall be incorporated into the design of the ground grids. Each ground test station shall be connected to the ground grid by at least two grounding conductors.
- Ground test stations shall be located so that they are accessible to Operations and Maintenance (O&M) personnel. Locations shall be chosen that minimize the bonding conductor length.
- Supplemental electrodes (at equipment) shall not be permitted.
- The ground grid shall be bonded to the ac service ground electrode and the structural steel of the building structure.
- Ground grid locations shall be coordinated with landscaping plans to avoid conflicts with tree roots, and with underground utilities and sewer installations to avoid any direct electrical connection to these systems.
- Ground grids shall be designed to allow up to 50 percent additional ground rods to be driven and attached to the grid in the future.

22.3.1.1 Ground Busbars

Unless otherwise specified, a single ground busbar shall be provided in each equipment room and pre-engineered enclosure (e.g., traction power facility (TPF) equipment houses, communications rooms, ATC/signal houses, and wayside power control cubicles). Ground busbars shall comprise a solid copper grounding busbar with insulated standoffs, and each ground busbar shall be drilled with rows of holes according to National Electrical Manufacturers Association (NEMA) standards, for attachment of bolted compression fittings.

Additional ground busbars for equipment shall be provided such that no potential equipment location within an auxiliary space (housing the equipment) is more than 30 feet from the nearest ground busbar.

Ground conductors at ground busbars shall be identified as to which system they are connected.

The ground busbars shall be connected to the ground electrodes or ground grids as detailed in Section 22.5.

22.3.1.2 Non-buried Grounding Conductors

Non-buried conductors between the ground grid or ground busbar and the grounded equipment shall be insulated copper wire or cable in non-metallic conduit. Grounding and bonding conductors shall be sized in accordance with the applicable code, so they can pass the maximum ground fault current without melting or fusing before the circuit breakers or protective relays disconnect the source of the fault current.

Non-buried grounding conductors shall be protected against physical damage and accordingly routed in conduit, cable tray systems, cable troughs, and/or ductbank systems under the following scenarios:

- Between buried ground grids and ground test stations.
- Between ground test stations.
- Between ground test stations and grounding busbars.
- Between equipment enclosures and grounding busbars.
- Between equipment enclosures.
- Along the trackside.

22.3.1.3 Publicly Accessible Locations

For locations that are accessible to the public, the following constraints shall apply to the grounding and bonding design:

- Anchor bolts and ground lugs shall not protrude in a manner that could result in injury or property damage.

- Materials shall be concealed wherever possible.
- Ground test stations in public areas shall be avoided.
- Tamper proof hardware shall be used.

22.3.1.4 Grounding Connections

Exposed grounding and bonding connections at equipment, enclosures, ground busbars, ground test stations, and so forth shall be visible and accessible. Two-hole compression-type termination lugs shall be used to connect bonding conductors to equipment enclosures.

Buried/underground joints in grounding conductors and connections shall be exothermically welded. Connections to reinforcement steel shall be exothermically welded. The steel reinforcement in the structure elements shall be interconnected electrically by means of exothermic welds and shall be electrically continuous. Epoxy coated rebar cannot be used as a grounding conductor. Where epoxy coated rebar is used as the only type of reinforcement, alternate grounding measures, such as connecting grounding plates directly to a series of buried ground rods or a ground grid, shall be adopted to achieve the required ground resistance of 25 ohms. Where epoxy coated rebar is used in combination with black rebar, the black rebar shall be interconnected to provide an electrically continuous path, with connection(s) to grounding plate(s), but with no connection to the epoxy bar. The required ground resistance of 25 ohms shall be achieved, if necessary by connecting the grounding plate(s) directly to buried ground electrodes. Splices in grounding conductors will not be permitted.

Equipment enclosure doors shall be bonded with flexible metal bonding straps, instead of reliance on hinges for electrical continuity.

Where identical installations exist, the following requirements apply wherever practicable:

- The routing of conduit and conductors between structures and enclosures shall not differ.
- Conductor terminations shall be located in like manner.

Prescribed materials, cables and appurtenances shall be compliant with Underwriters Laboratories, Inc. (UL) standards.

The color of the insulation jacket of insulated ground conductors shall be green.

Water, gas or other piping shall not be utilized as a ground electrode or ground conductor.

22.3.1.5 Electromagnetic Compatibility

For electromagnetic compatibility considerations, provide:

- Proper grounding and bonding of apparatus, conductor shields, and raceways to maximize shielding and to minimize circulating currents in shields.
- Surge protection against lightning and other natural sources of Electromagnetic Interference (EMI).

- Additional requirements are specified in the *Electromagnetic Compatibility and Interference* chapter and in the Standard and Directive Drawings and Performance Specifications.

22.4 Maximum Permissible Step and Touch Potential

Step and touch potential at the traction power facilities and facility power electrical rooms and/or yards shall be governed by the requirements of IEEE 80: Guide for Safety in AC Substation Grounding.

The bonding and grounding of current carrying equipment, enclosures and associated structures, including the Overhead Contact System (OCS), rails, and other trackside equipment, shall be designed such that the touch voltages do not exceed the values indicated in Table 22-1, which has been derived from EN 50122-1: 2011 Section 9.2.2:

Table 22-1: Durations of Maximum Permissible Touch Voltages

Duration of Current Flow (sec)	Permissible Voltage in V (rms)
0.02	865
0.05	835
0.1	785
0.2	645
0.3	480
0.4	295
0.5	220
0.6	180
< 0.7	155
0.7	90
0.8	85
0.9	80
1.0	75
≤ 300	65
> 300 (where accessible to the public under all power supply feeding conditions)	60
> 300 (in workshops and similar locations)	25

22.5 Grounding and Bonding Requirements for Facilities/Buildings and Structures

22.5.1 General Requirements

Structure grounding and bonding shall create a conductive path that will achieve potential equalization of the grounded elements of the railway system. Grounding connections provide for tying wayside metallic parts to the return circuit and for the electrical interconnection of reinforcing rods in concrete structures, and in case of other modes of construction, the conductive interconnection of the metallic parts. The structure grounding system provides grounding connections for:

- High/medium-voltage protective ground.
- Low-voltage protective ground.
- Communication and signaling systems.
- Lightning protection ground.

Any non-energized component of structures within the overhead contact line and pantograph zone (see Section 22.6.3) shall be either directly grounded or be bonded to the static wire to provide for personnel safety.

Bonding to pre-stressed steel tendons, within structures, is prohibited.

In addition to the following requirements, grounding provisions for particular facilities, buildings and structures are indicated in more detail in the Standard and Directive Drawings and Performance Specifications.

22.5.2 Facilities/Buildings

22.5.2.1 Service Entrance and Building Grounding

The ac grounding electrode system (otherwise known as “building ground”, “service entrance ground”) shall be designed to:

- Establish a common reference voltage for ac electrical power systems
- Provide a safe dissipation path for lightning and/or accidental high-voltage contact
- Provide a safe dissipation path for electrostatic discharge.

The components that make up the ac grounding electrode system include:

- Grounding electrode system (ground rod or ground grid)
- Grounding electrode conductor
- Bonding Conductor connects equipment grounding systems to the ac grounding electrode

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A ground grid (see Section 22.3.1 for requirements), in direct contact with the earth at a depth below the earth surface of at least 3 feet, shall be provided at each building. The ground grid shall extend at least 2 feet beyond the foundation footer and at least 1 foot 6 inches outside the roof drip line.

The metal frame of buildings shall be bonded to the ground grid. Connections to the ground grid shall be exothermically welded. Where exothermic welding is impractical, UL listed connection hardware may be used.

For steel-frame buildings, alternate vertical columns shall be bonded to the ground grid.

22.5.2.2 Building Exterior and Interior Bonding and Grounding

Each grounding conductor that passes through a structure, foundation or wall shall be provided with a waterstop.

Multiple separate grounding systems are not permitted within the same building. Where a building is supplied by two or more services, the grounding electrodes for the two services shall be bonded together.

In multi-floor buildings, the grounding conductor shall be extended to each floor.

Provide a grounding electrode conductor sized in accordance with the applicable code between the service equipment ground bus and metallic water and gas pipe systems, building steel, and supplemental or made electrodes. Jumper insulated joints and bolted (non-welded) joints in the metallic piping.

Bond the steel columns to the reinforced steel within the building foundation.

Conductive piping systems shall be bonded to the building grounding system. Bonding connections shall be made as close as practical to the equipment ground bus.

Within a building, the grounding cable shall, where possible, be embedded in or underneath the floor slabs. Attach and bond the grounding electrode system to non-current-carrying conductive entities within the building.

22.5.2.3 Raised Floor Systems

A signal reference grid (SRG) shall be provided for raised floor systems in compliance with IEEE 1100 and with the requirements of the *Electromagnetic Compatibility and Interference* chapter.

Connect the SRG to the facility grounding electrode system.

Where raised floor systems are of bolted metal stringer construction and are electrically continuous, two connections only to facility grounding electrode system shall be required.

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22.5.2.4 Trackside Facilities Including Sump Pump Structures, Ventilation Structures and Portal Facilities

See Sections 22.5.2.1 and 22.5.2.2 for the Grounding and Bonding requirements for these facilities. For the Grounding and Bonding requirements at the Tunnel Portals for reinforced concrete paved areas of Train Surface Evacuation and Fire Control Zone see Section 22.5.6, and for the Emergency Walkways see Section 22.5.3.

22.5.2.5 Rolling Stock Maintenance Buildings Including Heavy Maintenance Facility and Terminal Layup/Storage and Maintenance Facilities

See Sections 22.5.2.1 and 22.5.2.2 for requirements.

Where the catenary passes through the rolling stock maintenance buildings, catenary grounding devices shall be provided at building entrance points. These shall be in the form of three-position disconnect switches, providing for Closed (to interconnect to the adjacent elementary electrical section), Open (no electrical interconnection), and Closed to Ground, with one disconnect per shop track elementary electrical section and with inter-linked indication lights on a per elementary electrical section basis. The inter-linked lights shall be positioned above each shop catenary section and shall permit maintenance personnel to be able to see clearly which sections of the OCS are energized and which are grounded. The disconnect handles shall be provided with bars that will accept multiple locks so that more than one maintainer can apply his/her personal lock to ensure the switches cannot be operated while someone is working.

The catenary disconnect switch grounding shall be electrically isolated from the building and associated facility electrical grounding system. The OCS static wire shall not be electrically interconnected to any conductive facility structure or to the facility grounding system.

22.5.2.6 Maintenance of Infrastructure Facilities

See Sections 20.5.2.1 and 20.5.2.2 for the Grounding and Bonding requirements for Maintenance of Infrastructure (MOI) facilities.

22.5.3 Grounding and Bonding of Structures - General

Except for passenger station and service track platforms, metallic items on structures crossing over, under or immediately adjacent to the electrified tracks shall be bonded either directly or indirectly to a static wire and/or to a trackside grounding plate for personnel safety and lightning protection. The steel reinforcement in the structure elements discussed in the following sections, including the viaduct parapets, shall be interconnected electrically by means of exothermic welds and shall be electrically continuous. Epoxy coated rebar cannot be used as a grounding conductor. Where epoxy coated rebar is used as the only type of reinforcement, alternate grounding measures, such as connecting grounding plates directly to a series of buried ground rods or a ground grid, shall be adopted to achieve the required ground resistance of 25 ohms. Where epoxy coated rebar is used in combination with black rebar, the black rebar shall be interconnected to provide an electrically continuous path, with connection(s) to grounding

plate(s), but with no connection to the epoxy bar. The required ground resistance of 25 ohms shall be achieved, if necessary by connecting the grounding plate(s) directly to buried ground electrodes. The grounding and bonding of the emergency walkway area and other publicly accessible areas, as well as grounding and bonding of the track structure (where appropriate), shall be designed to avoid inadmissible touch and step voltages and also to meet the requirements of the signaling system.

22.5.4 Aerial Structures (Viaducts and Underbridges)

22.5.4.1 Concrete Structures

For concrete aerial structures, over which the high-speed trains run, the static wire shall be electrically grounded through the aerial structure columns and/or the abutments. The reinforcement steel in the support column foundation shall be electrically connected to the reinforcement steel of the column, a jumper from which shall be connected with an exothermic weld to a surface-mounted grounding plate near the top and bottom of and on both sides of the column – a total of four plates per column. Only one plate on each side of the column will be required when the upper plate will be five feet or less above finished grade at the column. The jumpers, both internal between rebar and grounding plates and external between grounding plates, shall be a minimum size of 4/0 AWG copper, but alternate materials, such as aluminum angle of comparable electrical capacity, may be adopted. Appropriate measures shall be adopted where dissimilar metals are interconnected. The structures contractor shall ensure that the ground resistance, measured at this plate prior to any further connections as detailed below, shall be 25 ohms or less. Where the resistance is greater than 25 ohms, the structures contractor shall install additional grounding measures to achieve this value.

The reinforcement steel in concrete aerial structure segments or beams shall be interconnected and similarly jumper-connected to a surface-mounted grounding plate at each end of and on both sides of and near the bottom of the segment/beam (four plates total), such that an external jumper can be installed to electrically connect the column and segment/beam grounding plates. For viaduct beams that are 200 feet or less in length, a grounding plate that is electrically bonded to the reinforcing steel shall be installed at or close to the midpoint of each beam on the inner surface of both parapet walls, and on the upper surface of the beam for connection to the track slab grounding plates. For viaduct beams that are more than 200 feet in length, additional grounding plates shall be installed such that the along track spacing between plates is a maximum of 200 feet. The structure contractor shall ensure there is electrical continuity between the grounding plates on each beam prior to any further connections being made. The structure contractor shall then connect the grounding plates at one end of the beam only to the grounding plates at the top of one column only, and shall check and ensure that the grounding resistance is equal to or less than 25 ohms. The systems contractor shall subsequently recheck the resistance and, providing it is equal to or less than 25 ohms, shall connect the beam-column jumpers at the remaining end of the beam.

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The parapet grounding plates shall be used for exothermically welded grounding connections to the OCS poles and to other systems elements, such as ATC and communications cubicles or houses, and wayside power control cubicles.

22.5.4.2 Steel Structures

For steel girder structures, over which the high-speed trains run, the static wire shall be electrically grounded by means of jumpers with bolted lug connections to the OCS pole baseplates and exothermic weld connections to the grounding plates on the structure columns and/or abutments. The steel bridge girders shall be interconnected at the "fixed ends" with exothermically welded flexible bonds, which shall be connected to the reinforcement steel (within the bridge piers or abutments) at two grounding plates, each with a ground resistance of 25 ohms or less, similar to the requirements indicated above for the concrete structures. To provide electrical continuity at the "sliding end', the two outer girders shall each be connected by an exothermically welded flexible jumper (of sufficient length to allow for expansion and contraction of the girders) to a grounding plate that is connected to the reinforcement steel (within the bridge pier or abutment). Where non-ballasted track is installed on the steel support structures, flexible jumpers shall be exothermically welded between the track slab grounding plates and the steel support girders.

22.5.5 Track Support Structure

Steel reinforcing bar (rebar) loops in concrete supporting running rails can cause inductive loading or undesired coupling between track circuits. To avoid these adverse effects, all rebar in any structure that is within 1 foot of a CHST running rail shall be grounded in one of the following configurations. The Contractor shall determine the most appropriate configuration and shall use the same configuration in all similar applications. Structures to be treated include track slabs, viaduct decks, etc.:

- Long comb – In each affected structure, longitudinal rebars (those parallel to the running rails) are electrically connected in a 'comb' pattern to a single lateral (perpendicular to the running rails) connecting rebar at one end only of the longitudinal rebars. The lateral connecting rebar shall be connected to an external connection to the reinforcement that is connected to a grounding plate. The other lateral rebars shall be ungrounded and insulated from the longitudinal rebars at their intersections.
- Short comb – In each affected structure, lateral rebars shall be electrically connected in a 'comb' pattern to a single longitudinal connecting rebar at one end only of the lateral rebars. The longitudinal connecting rebar shall be connected to an external grounding plate. The other longitudinal rebars shall be ungrounded and insulated from the lateral rebars at their intersections.
- Double comb – In each affected structure, longitudinal rebars shall be electrically connected in a 'comb' pattern to a single lateral connecting rebar at one end of the longitudinal rebars. The lateral connecting rebar shall be connected to an external grounding plate. The other lateral rebars shall be connected in a 'comb' pattern to a single longitudinal rebar. The

longitudinal connecting rebar shall be connected to an external grounding plate. The longitudinal and lateral rebars shall be insulated at their intersections, and shall be only connected together through their grounding connection.

If a structure contains multiple layers of rebar within 1 foot of a running rail, each layer shall be treated in one of the above configurations.

If a structure contains multiple layers of rebar, layers that are greater than 1 foot from any running rail can be grounded in any pattern that satisfies the safety requirements for grounding and bonding.

22.5.5.1 Non-Ballasted Independent Dual Block Track

In this form of track construction, the independent blocks, which are supported by non-reinforced track concrete, provide no electrical interconnection through which traction current would flow. However, the reinforcement in the cast-in-place concrete slab could become part of the return circuit and shall be grounded and bonded in a manner similar to that for the aerial structure beams/segments.

The grounding design shall ensure the maximum permissible touch voltages, as specified in Table 22-1, are not exceeded.

22.5.5.2 Non-Ballasted Precast Concrete Slab Track

In this form of track construction, the reinforced precast segmental slabs, which are supported by non-reinforced asphaltic material, could provide an electrical path through which traction current may flow. In addition, the reinforcement in the cast-in-place concrete slab could become part of the return circuit. Therefore, the reinforcement in the precast segmental slabs shall be inter-connected to the reinforcement in the cast-in-place concrete slab and shall be grounded and bonded in a manner similar to that for the aerial structure beams/segments.

The grounding design shall ensure the maximum permissible touch voltages, as specified in Table 22-1, are not exceeded.

22.5.6 Passenger Station and Service Siding Platforms

22.5.6.1 Passenger Stations and Service Siding Platforms in At-grade, Cut-and-Cover Tunnel, or Trench Locations

For at-grade platform grounding, a counterpoise shall be installed along the entire length of each platform with the conductor buried in earth and extending a minimum of 50 feet beyond the ends of the platform, with intermediate ground rods driven and interconnected at not more than 50-foot intervals. For cut-and-cover tunnel or trench located platform grounding, where the structure is protected by waterproof membranes, an in-ground counterpoise cannot be installed. For these locations, a bare grounding conductor shall be installed along the entire length of each platform with intermediate connections to the platform reinforcement at not more than 500-foot intervals and with the conductor extending a minimum of 50 feet beyond

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the ends of the structure buried in earth and connected to driven ground rods. The grounding conductor shall be a minimum size of 4/0 AWG copper, but alternate materials, such as aluminum angle of comparable electrical capacity, may be adopted. Appropriate measures shall be adopted where dissimilar metals are interconnected. One end of the counterpoise or grounding conductor shall be terminated in a handhole, which will permit the counterpoise or grounding conductor to be connected to the rails via an impedance bond, with the location being coordinated with the ATC System designer. Metallic structures and miscellaneous metallic items within 8 feet from the edge of the platform (including platform reinforcement steel and any OCS poles) shall be isolated from the static wire and shall be bonded directly or indirectly to the counterpoise or grounding conductor. The counterpoise- or grounding conductor-bonded metallic items shall be isolated from steel building grounds and particularly from utility grounds.

The grounding design shall ensure the maximum permissible touch voltages, as specified in Table 22-1, are not exceeded and, without exception, the resistance to ground shall not exceed 5 ohms. Subject to field testing during construction, it may be necessary to install supplemental ground rods at the ends of the counterpoise to achieve the 5 ohm value, and the designer shall incorporate this requirement in the design.

See Sections 22.5.2.1 and 22.5.2.2 for the Grounding and Bonding requirements for facility power installations in passenger stations.

22.5.6.2 Passenger Station Platforms in Aerial Structures

The station buildings, including the platforms, will be constructed to be structurally independent from the aerial trackway. The facility electrical system will utilize insulated cable grounding connections to the electric utility supply point. See Sections 22.5.2.1 and 22.5.2.2 for the Grounding and Bonding requirements for facility power installations in passenger stations.

To minimize step and touch potentials between the station platform and the vehicles, the platform reinforcement shall be electrically interconnected and shall be connected to the rails through an impedance bond at one end only, as detailed above for the at-grade platforms. The reinforcement in the platform shall be electrically interconnected to the reinforcement in the supporting structure and its foundation reinforcement. If the platform is constructed using pre-cast panels, grounding plates (as detailed above for the aerial structures) shall be used to provide the means for interconnecting the reinforcement in the panels and for attachment of the impedance bond connection. Provisions shall be incorporated into the platform design such that all metallic structures and miscellaneous metallic items within 8 feet from the edge of the platform (including any OCS poles) shall be isolated from the static wire and shall be bonded directly to the platform reinforcement. The platform reinforcement-bonded metallic items shall be isolated from the facility and utility grounds.

The grounding design shall ensure the maximum permissible touch voltages, as specified in Table 22-1, are not exceeded and, without exception, the resistance to ground shall not exceed 5 ohms. Subject to field testing during construction, it may be necessary to install supplemental

ground rods outside the limits of the platform, which can be attached to the platform grounding system to satisfy the touch voltage requirements, and the designer shall incorporate this requirement into the design.

22.5.6.3 Elevated Access Platforms at Service Sidings

Metallic parts of elevated access platforms for rooftop equipment inspection and maintenance at service sidings shall be electrically interconnected and shall be connected to the rails through an impedance bond at one end only to minimize step and touch voltages between the access platform and the vehicles. Provisions shall be incorporated into the platform design such that all metallic structures and miscellaneous metallic items within 8 feet from the edge of the platform (including any OCS poles) shall be isolated from the static wire and shall be bonded directly to the platform. The platform-bonded metallic items shall be isolated from any facility or utility grounds.

The grounding design shall ensure the maximum permissible touch voltages, as specified in Table 22-1, are not exceeded. Subject to field testing during construction, it may be necessary to install supplemental ground rods outside the limits of the platform, which can be attached to the platform grounding system to satisfy the touch potential requirements, and the designer shall incorporate this requirement into the design.

22.5.7 Existing Overpasses

If components of existing overpasses, as detailed below, lie within the overhead contact line and pantograph zone, see Figure 22-1, the following special grounding provisions may be required to afford protection to adjacent third party installations:

- Abutments or Piers – galvanized steel strip on each bridge wall or attached to columns of piers.
- Bridge Face – galvanized steel strip or angle section above the overhead line at each bridge face, if the bridge soffit is within the pantograph zone.

The above measures shall be provided at existing structures if an analysis determines the need for them.

When the vertical clearance between OCS conductors and concrete overpasses is less than 3 feet, protection panels (flash plates) shall be installed above the OCS, attached to the underside of the structure, and interconnected to the static wire at not less than two locations. For steel overpasses, the steel girders shall be interconnected and bonded to the static wire at not less than two locations.

Publicly accessible overpasses shall be protected by screening and/or barriers which shall be at least 8 feet high and extend laterally beyond the live parts of the overhead contact line by at least 10 feet on each side. The metallic portion of the screening and barriers shall be bonded to the static wire at not less than two locations. All other metallic items on the overpass, within the

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lateral range of not less than 10 feet beyond any energized and uninsulated equipment passing below the structure, shall be directly or indirectly bonded to the static wire.

22.5.8 New Overpasses

Grounding and bonding for concrete beam and steel beam structures, and their supporting abutments or piers, shall be as detailed above for the aerial structures, and shall include provision of grounding plates for connections to the static wire(s).

Where the headroom at new overpasses is less than the preferred minimums for structures over either dedicated or shared use segments of the route, as shown in the Contract Documents, some of the measures detailed in Section 22.5.7 may have to be implemented. If components of new overpasses lie within the overhead contact line and pantograph zone, see Figure 22-1, the provision of flash plates may be required when the vertical clearance between OCS conductors and concrete overpasses is less than 3 feet, attached to the underside of the structure, and interconnected to the static wire at not less than two locations. For steel overpasses, the steel girders shall be interconnected and bonded to the static wire at not less than two locations.

Publicly accessible overpasses shall be protected by screening and/or barriers which shall be at least 8 feet high and extend laterally beyond the live parts of the overhead contact line by at least 10 feet on each side. The metallic portion of the screening and barriers shall be bonded to the static wire at not less than two locations. All other metallic items on the overpass, within the lateral range of not less than 10 feet beyond any energized and uninsulated equipment passing below the structure, shall be directly or indirectly bonded to the static wire.

22.5.9 Trenches, Retaining Walls, and Retained Fill Structures

The reinforcement steel in the trench walls shall be electrically connected to the reinforcement steel of the base slab, and successive trench segments shall be connected together to provide electrical continuity. For trench structures, where the structure is protected by waterproof membranes, a bare grounding conductor shall be installed along the entire length of both sides of the structure with intermediate connections to the structure reinforcement at not more than 500-foot intervals. At these connection points, the grounding conductor shall be connected to buried electrodes, driven into the ground outside the trench structure, and each grounding point shall achieve a resistance of 25 ohms or less. To satisfy this requirement, the contractor may opt to install additional grounding plates on the top of the trench walls. The grounding conductor shall be extended a minimum of 50 feet beyond the ends of the structure (buried in earth) and connected to driven ground rods. The grounding conductor shall be a minimum size of 4/0 AWG copper, but alternate materials, such as aluminum angle of comparable electrical capacity, may be adopted. Appropriate measures shall be adopted where dissimilar metals are interconnected. The reinforcement steel in retaining walls or retained fill structures shall be similarly electrically connected to the reinforcement steel of the footing, and successive retaining wall or retained fill structure segments shall be interconnected to provide electrical continuity. The static wire shall be electrically grounded through the trench or

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retaining wall or retained fill structure reinforcement via surface-mounted grounding plates, with a ground resistance of 25 ohms or less, as detailed for the aerial structures. To facilitate grounding of the track slab, grounding plates, electrically interconnected to the structure reinforcement, shall be installed in the face of the walkway. Grounding plates, electrically bonded to the reinforcing steel, shall be provided at no more than 10 feet from each end of, and in each niche/recess in, trench and retaining wall structures, and at intervals not to exceed 200 feet +/-10 feet for all structure types. Systems elements, including ATC and communications cubicles or houses, wayside power control cubicles, and facilities electrical equipment, shall be grounded to these plates.

For long trenches or retaining wall segments, particularly those cut into rock, the systems designer shall determine whether additional grounds and/or an additional along-track ground wire(s) may be required to meet the ground resistance requirements and/or to minimize the possibility that rail potentials may cause unacceptable touch voltages and shall incorporate such into the design as needed. If any additional ground conductors are laid at low level—adjacent to the track or along the walkways—these conductors will also supplement the grounding capability of the system and enhance fault detection and control in the event of a broken wire condition. In order to provide a sufficiently low ground resistance, it may be necessary to install a ground grid at or near to the end(s) of the trench or retaining wall segment.

22.5.10 Tunnels

For tunnel sections, metallic drop pipes or brackets, which support the OCS cantilevers, shall be bonded to the static wire and, dependent on tunnel length and the requirements of the ATC system, the static wire shall be connected to rail through impedance bonds in the same manner as for surface sections. For tunnels, particularly those cut into rock, the systems designer shall determine whether additional grounds and/or an additional along-tunnel ground wire(s) may be required to meet the ground resistance requirements and/or to minimize the possibility that rail potentials may cause unacceptable touch voltages and shall incorporate such into the design as needed. Any required additional ground conductors shall be laid at low level—adjacent to the track or along the outer edges of the walkways—so these conductors will supplement the grounding capability of the system and enhance fault detection and control in the event of a broken wire condition. Based on the rail potential analysis and in order to provide a sufficiently low ground resistance, it may be necessary to install a ground grid at or near one or both tunnel portals.

Where the reinforcing rods in the tunnel structures can be interconnected longitudinally, such as in cut-and-cover construction, or the tunnel is built in sections (with gaps along the length), each section shall be connected to the return circuit static wire, or the sections shall be connected together and then connected to the static wire, utilizing grounding plates where appropriate—mounted at the interior surface of the tunnel—as detailed above for the aerial structures. To facilitate grounding of the track slab, grounding plates, electrically interconnected to the structure reinforcement, shall be installed in the face of the walkway.

Grounding plates, which shall be electrically bonded to the static wire, shall be provided at no more than 10 feet from each end of, and in each niche/recess in, tunnels and at intervals not to exceed 200 feet +/-10 feet.

Ground connections for facility services within tunnels shall provide an exposed ground conductor (sized per Code (NEC and CEC)) parallel to each track for the complete length of the tunnel and interconnected (by at least two connections) to each building (e.g., ventilation structures, portal facilities, sump pump structures) ground grid associated with the tunnel structure. Where the tunnel structure design includes cross passages, emergency shafts and so forth, the ground conductor shall be extended into these spaces. The ground conductors shall be located to avoid accidental contact by personnel.

22.5.11 Screen/Noise/Wind/Safety Barriers

The reinforcement steel of screen, noise, wind and/or safety barriers shall be electrically connected to the reinforcement steel of the associated structure (e.g., aerial structure, trench) in a similar manner to that detailed above for aerial structures.

Safety barriers shall be electrically bonded to the static wire at not fewer than 2 locations.

22.5.12 Fence and Gate Grounding

The designer shall evaluate touch voltages on metallic fences and/or gates, including inter-track fences, which lie within the Overhead Contact Line and Pantograph Zone (Figure 22-1). Ground electrodes shall be installed on either side of a gate or other opening in the fence. Fence posts at openings in the fence shall be bonded to form a continuous path, and gates shall be bonded to support posts with flexible metal bonding straps to eliminate reliance on hinges for electrical continuity. Fences shall be made electrically continuous and grounding conductors shall be exothermically welded to fence posts and to any fence material support members (top and bottom) between posts. Metallic fences inside the Overhead Contact Line and Pantograph Zone (Figure 22-1) shall be electrically bonded to the static wire and segmented (electrically insulated) at intervals such that the touch voltage does not to exceed the limits specified in Table 22-1.

Metallic fences outside the Overhead Contact Line and Pantograph Zone (Figure 22-1), up to a distance of 45 feet from an outside track centerline, shall be bonded to form a continuous path in the same manner as detailed above. Ground electrodes shall be installed on either side of a gate or other opening in the fence, and at intermediate locations, based on local soil resistivity and worst case projected potentials. Grounding conductors shall be exothermically welded to fence posts and to driven ground electrodes.

22.5.13 Third-Party Grounding Interface

Due to the danger of voltage propagation, third-party grounding installations in the vicinity of the ROW shall not be connected to the railway grounding system. For third-party pipework,

non-conducting materials shall be used or an insulating segment or insulated joint shall be inserted at the site boundary. Where the public network grounding system cannot be separated from the railway grounding system due to lack of space for separation, the traction power return circuit shall be interconnected with the neighboring grounding system of the public network.

To minimize the possibility of shock hazards outside the fence line, the systems designer shall evaluate touch potentials on third-party metallic fences/gates and/or pipelines that parallel the ROW, or other metallic structures. The systems designer shall provide designs for grounding and/or segmenting the conductive feature using insulating measures for these elements, such that touch potentials are controlled to levels that do not exceed the limits detailed in Table 22-1. Fences, and/or segments shall be made electrically continuous, but shall not be connected to railway ground grids, grounding conductors, static wires, or the rails, and shall be independently grounded by means of driven ground rods. Grounding conductors shall be exothermically welded to fence posts and to driven ground electrodes.

In cases where fences are purposely electrified to inhibit livestock or wildlife from crossing the fence, site-specific insulating measures shall be designed and implemented.

Connections to third-party infrastructure shall be coordinated and approved by the third party. Refer also to Section 22.12 and to the *Utilities* chapter.

22.6 Grounding and Bonding Systems for the Traction Electrification System Equipment and Structures

22.6.1 General

The rail return path of the 2x25 kV ac autotransformer feed Traction Electrification System (TES) consists of the static wires, the running rails, cable connections from static wires/running rails to the TPF (all of which are grounded as detailed below) and the earth. The static wire is connected at regular intervals to the running rails, via impedance bonds, and to the (grounded) center tap of the secondary winding of each traction power transformer and the (grounded) center tap of the winding of each autotransformer, using two independent connections. The static wire runs alongside the catenary to interconnect the OCS supporting structures and brackets, such that all normally non-current-carrying metallic supports of the OCS are at the same ground (and track) reference potential.

The traction return current causes a voltage rise in the running rails and static wires, due to the impedance of these conductors, for both normal operations as well as under short circuit conditions, thereby resulting in a voltage between the running rails and static wires and the surrounding ground or other grounded metallic parts (touch voltage). These touch voltages shall be limited to acceptable values. Hazards due to touch voltages shall be minimized by means of adequate grounding and bonding measures, and as required, mitigation measures.

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For a more detailed description of the (TES), refer to the *Traction Power Supply System* and *Overhead Contact System and Traction Power Return System* chapters.

The overall grounding and bonding protection for the TES shall consist of the OCS aerial static (ground) conductors, connections from the aerial ground conductors to any buried ground conductor/ground rods and the impedance bonds connected to the track, with connections between these elements and each TPF ground grid. In addition to the impedance bond connections at the TPFs, additional connections between the static wires and the rails through impedance bonds may be needed, based on the traction power load flow simulation results and the step and touch analysis. The designer shall determine the required spacing of the impedance bonds and interconnections to the rails, which must be coordinated with the operating requirements of the ATC System.

Where insulated cables are used within the TES, they shall be specified and manufactured in accordance with the appropriate electrical standards that are applicable to the working environment—voltages, operating and fault currents—to which they will be subjected.

The OCS grounding and bonding system shall interconnect all OCS normally-non-current-carrying metallic parts and shall bond metallic components of overhead bridges, tunnels and other structures.

The grounding and bonding system for the TES shall not be electrically connected to any non-traction power facility electrical grounding system.

22.6.2 Traction Power Facilities

See Section 22.5 for general ground grid requirements.

The ground grid for each TPF shall be in direct contact with earth at a depth of 12 to 18 inches below grade, as stipulated in IEEE-80: 2000, Section 9.2. The ground grid shall be extended at least 2 feet beyond the fence of the TPF. The ground grid for each TPF shall be designed per the specifications of IEEE-80, NESC, CEC and NEC.

The metal fence of the TPF shall be bonded to the TPF ground grid as specified in the applicable code.

A layer (3 to 6 inches thick) of high resistivity material, such as gravel, shall be spread on the earth's surface above the ground grid to increase the contact resistance between the soil and the feet of persons in the TPF. The grounding system shall be designed so that the step and touch potentials under fault conditions are within the designated limits.

In areas where soil resistivity is high or the TPF space is limited, alternative methods shall be considered for obtaining low impedance grounding, such as connections to remote ground grids or wire mesh, deep-driven ground rods or drilled ground wells, plus the use of various additives and soil treatment methods, etc. The effects of transferred potentials, which can result from interconnection to remote ground grids, shall be considered.

Wayside power cubicles (WPC) in at-grade locations shall be grounded by separately driven ground rods at opposite corners, which are to be connected to grounding pads on the enclosure. For aerial locations and in tunnels, trenches, retaining wall and retained fill structures, the WPC shall be grounded by two interconnections to a grounding plate (as detailed above for the aerial structures).

22.6.3 Overhead Contact System

OCS structure grounding and bonding should create a conductive path that will achieve potential equalization of the grounded elements of the railway system. Grounding connections provide for tying wayside metallic parts to the return circuit and for the electrical interconnection of reinforcing rods in concrete structures, and in case of other modes of construction, the conductive interconnection of the metallic parts. The structure grounding system provides grounding connections for the following:

- High/medium-voltage protective ground
- Low-voltage protective ground
- Grounding of telecommunication and signaling systems
- Lightning protection ground

The OCS poles shall be grounded through interconnection of the pole to the static wire so that the ground resistance of the interconnected poles is kept low. Reinforced concrete and anchor bolt foundations, where the concrete is in good contact with the adjacent soil, are recognized as being good earth electrodes. Where the ground resistance of individual OCS poles exceeds 25 Ω, individual ground rods or other grounding solutions shall be applied. All other OCS structural supports—wall brackets, drop pipes, feeder wire brackets, etc.—shall be interconnected to the static wire.

Ground connections to disconnect switches and ground leads from surge arresters shall have a maximum ground resistance of 5 ohms. Ground rods or a ground mat may be utilized to obtain the required ground resistance. If the metallic OCS pole at the disconnect switch location is to be used as part of the grounding system, the pole must be bonded to the steel reinforcement in the concrete pier foundation, and the reinforcing steel bonded to one or more driven ground rod(s) and/or the ground mat.

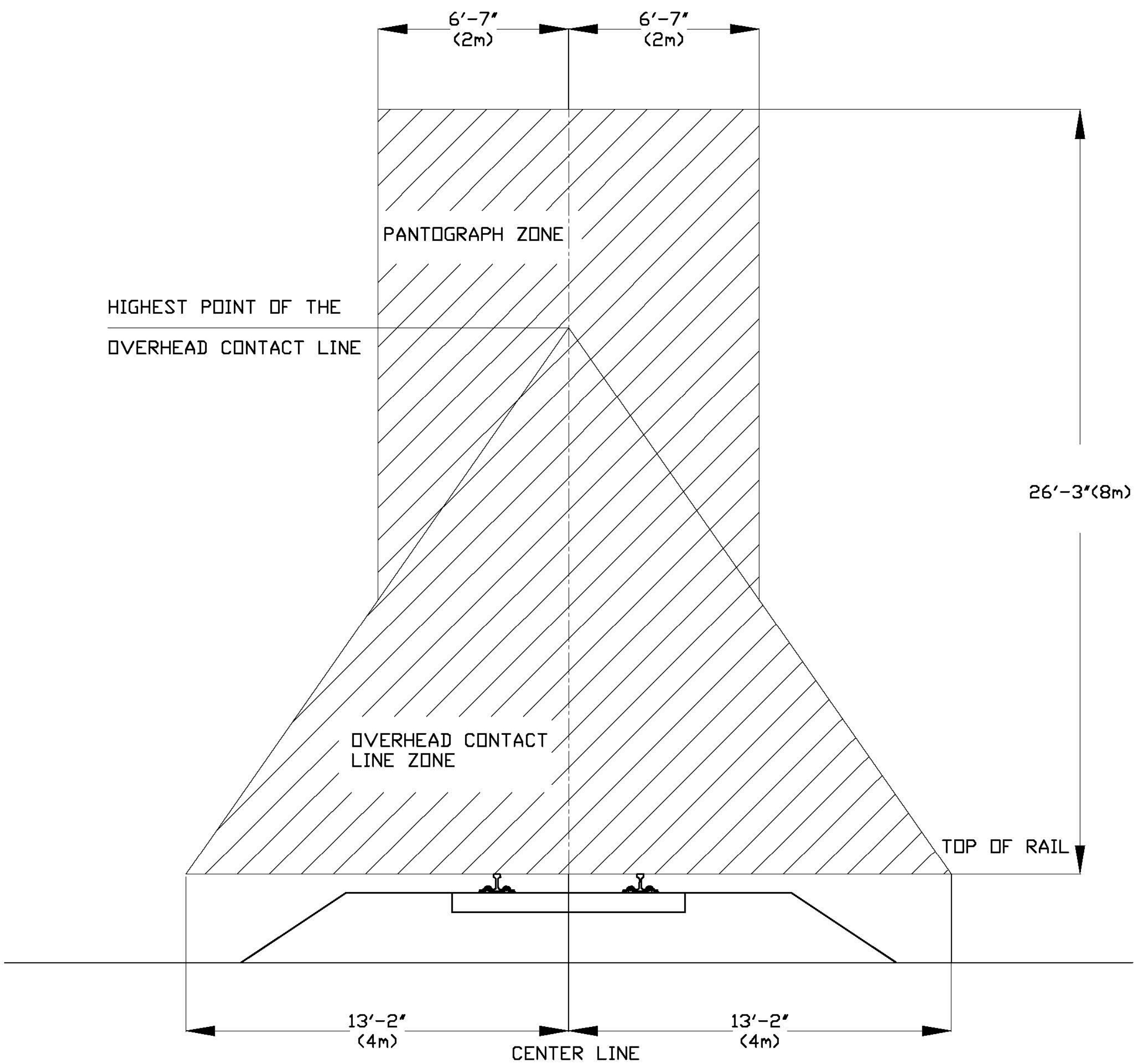
See Section 22.7 for additional requirements.

A live broken contact line, or live parts of a broken or de-wired pantograph or energized fragments, may accidentally come into contact with wayside structures and equipment. Figure 22-1 defines the zone inside which such contact is considered probable and which limits are unlikely to be exceeded, in general, by a broken overhead contact line or damaged energized pantograph, or energized fragments.

The limits of the overhead contact line zone below top of rail extend vertically down to the earth surface, except where the tracks are located on a viaduct where they extend down to the viaduct deck. In the case of energized out-of-running OCS conductors, the overhead contact line zone shall be extended accordingly.

Non-current-carrying metallic components that lie within the overhead contact line and pantograph zone shall be either directly grounded or bonded to the static wire to provide for personnel safety.

Figure 22-1: Overhead Contact Line Zone and Pantograph Zone



22.6.4 Return System

The ground grid at each traction power facility, and the center tap of the secondary of main power transformers and the center tap of autotransformers, shall be connected to the traction power facility ground bus. The ground bus shall be connected to the rails through impedance bonds, and to both static wires through two independent connections. The return cable shall be sized to carry the maximum load current, thereby allowing for the failure of one return cable. The static wire shall be connected at regular intervals to the running rails, via impedance bonds at locations approved by the ATC designer. Additionally the impedance bonds shall be cross-connected at intervals in both two-track and multi-track areas at a frequency that does not compromise the broken rail detection system.

This aspect of the grounding and bonding system design shall be coordinated between the Traction Power Supply System, OCS and ATC designs.

22.6.5 DC Traction Systems Adjacent to the Authority's Right-of-Way

Where tracks operated by dc traction power systems are located adjacent to the tracks, a considerable degree of coordination will be required with the dc traction system operator to minimize the possibility of creating dc stray current circuit paths through the ac system traction power return circuits. Track insulation between rails and ground shall be enhanced in these areas in compliance with the requirements of the *Trackwork* chapter.

The design of the TES shall minimize the possibility of creating dc stray current circuit paths through the return system. The static wire in the area potentially subject to dc stray currents shall be electrically insulated from the OCS poles by supporting the static wire on insulators. The OCS poles shall be grounded through interconnection of the pole, anchor bolts and steel reinforcement of the concrete foundation so that the ground resistance of individual poles is kept low, and does not exceed 25 ohms. Where the ground resistance of individual OCS poles exceeds 25 ohms, individual ground rods or other grounding solutions shall be applied. Fault conditions shall be evaluated and grounding designs shall be developed such that unsafe touch voltages are not created.

The designer shall monitor and document any dc stray current leakage from dc system tracks adjacent to the Authority's right-of-way/facilities during the design phase to establish baseline levels. Similarly, the contractor shall monitor and document any dc stray current leakage from the dc system tracks during the field testing and commissioning phase, to evaluate any differences and take any necessary remedial action to assure the integrity of the system.

Where passenger platforms and emergency walkways are located adjacent to dc system tracks, the designer shall investigate whether inadmissible touch voltages could occur between the rail and ground, and shall determine whether a voltage-limiting device, such as non-permanent rail to ground connection, should be installed to control touch voltages. If necessary, the designs shall require the contractor to install such devices.

All of the above measures shall be coordinated with the ATC System designer.

Early in the design phase, the Authority will have to coordinate with the dc electrified railroad operator to obtain assurance that the operator will maintain a high level of insulation between the dc system rails and ground in these sections to minimize the possibility of any dc stray currents leaking into the ac traction return system.

22.7 Grounding and Bonding Protection Systems for the Automatic Train Control System Equipment and Structures

22.7.1 Automatic Train Control Houses and Automatic Train Control Rooms

Ground grid and risers to the ATC rooms in stations shall be shall be included in the facilities design, and shall stub out 6 inches above the floor inside the ATC room.

Ground rods or ground grid and risers to the ATC houses and cases shall be provided by the ATC contractor where these units are located at grade.

The grounding system for ATC equipment shall be designed as a single-point ground system. Equipment safety grounding shall be designed to limit touch voltages to safe levels, as specified in Table 22-1, with and without a fault on the ac system.

Solid copper ground busbars designed for mounting on the framework of open or cabinet-enclosed ATC equipment racks shall be provided. Ground bars, within equipment racks, shall be bonded together using solid copper splice plates. All busbars and the metal structure of the houses and cases shall be bonded to the ground conductor, which in turn shall be bonded to the local ground provision (either ground rods or grounding plate integrated into the civil structures.

Bonding conductors shall be continuous and routed in the shortest, straight-line path possible.

AC and dc ground detectors shall be provided for each train control room and house, and the sensitivity shall be sufficient to detect a ground leakage resistance of 0 to 2,000 ohms for ac ground and 0 to 10,000 ohms for dc ground.

22.7.2 Trackside ATC Equipment and Structures

Grounding of wayside equipment and metallic structures, including houses and wayside cases, shall be localized as much as practical with ground rods driven into the earth as close to the equipment/structure as possible. Where the structure design prevents the use of ground rods, grounding plates and grounding conductor (as detailed above for the aerial structures, retained fill, trenches, and tunnels) to which the signal equipment shall be grounded, shall be included in the Infrastructure design. See Section 22.5 for further details of facilities, buildings and structure grounding requirements.

The ground resistance shall not exceed 15 ohms as measured from equipment to ground where the ground rods are provided by the Systems contractor and 5 ohms from equipment to the grounding plate connection provided by the Civil contractor.

The base of a ground-mounted signal mast or dwarf signal shall be bonded to the traction return system by direct connection to the neutral leads of an impedance bond adjacent to the signal. There shall be no other electrical connections between the signal mast and other structures or other rails or neutral leads unless specifically called for on the plan as part of an "A" point (see below).

Signal bridges or cantilever structures at a location that is not an "A" point (see below) shall not be electrically connected to any neutral leads or any portion of any track structure that is part of the signal system. These structures shall not be bonded to the static wire of the OCS, but shall be connected to ground rods in at-grade locations, or to grounding plates on aerial structures, in tunnels, or in trench/retaining wall locations.

22.7.3 Cross Bonding

In signaling systems using track circuits in which the block lengths are defined by insulated joints in the track, impedance bonds are employed to permit the traction return current in the rails to pass through a relatively low impedance on its way back to the substation, while at the same time presenting a very high impedance to the signal circuit. The connections to impedance bonds are configured in a variety of ways, as discussed below, and the bonds are usually installed at the insulated joints. The bonds are designed so that the center tap can be grounded or connected to a return conductor in the traction power return circuit.

The preferred locations for impedance bonds are at or in close proximity to the traction power facilities where the center tap is connected to the traction facility ground grid. Rail Potential Rise results from the flow of traction power return current in the rails and additional locations for impedance bonds are dictated by the need to minimize that potential rise within safe limits.

The preferred locations for all impedance bonds will be identified under the TP system design but must then be coordinated and confirmed by ATC designer who shall undertake the block design. Once the locations have been confirmed, the Trackwork Contractor, who shall supply the joints, will install the insulated joints at the agreed locations. The ATC Contractor shall supply and install the bonds, and the OCS Contractor will supply and install the center tap bond connections and the exothermically welded rail tap connections. The ATC Contractor shall supply and install the track circuit connections.

22.7.3.1 General Requirements

Impedance Bonds at Cross Bonding Locations shall be of two different configurations:

- An "A" point is defined as a location where impedance bond neutral leads on all tracks are bonded together, and to one or more OCS support structures which are in turn bonded to

the static return wires and, at traction power facilities (such as substations, switching stations, and paralleling stations) directly to the traction power facility return bus.

- A "B" point is defined as a location where the impedance bonds neutral leads connect two tracks together and are also connected to ground, but are not connected to the static wire or the traction power return bus.

Impedance Bonds at Other Locations shall be of two different configurations:

- A "C" point is defined as a location with impedance bonds that bypass insulated joints on one track but with no cross-bonding to adjacent impedance bonds or tracks, or to the OCS static wires.
- A drain bond is an impedance bond installed to connect the rails to traction power facilities, such as substations, switching stations, and paralleling stations, where no insulated joints exist in the tracks in the vicinity of the traction power facility. At such locations, the neutral leads of the drain bonds shall be connected directly to the traction power facility return bus. Drain bonds shall also be used at stations for connecting the platform counterpoise or grounding system to the rails where there is no adjacent “A” or “C” bond to which the platform grounds could be connected.

The purpose of cross-bond locations ("A” and “B” points) is to minimize step voltages on the rails to values that are less than the limits specified in Table 22-1. Cross-bond locations shall include a minimum of 2 track circuits between them and should, if practical, be located not less than 6,000 feet apart but not more than the permissible potentials will permit. The ATC designer shall coordinate the cross-bonding locations with the TES designers.

Where cross-bonds are more than 6,000 feet apart:

- Distance between cross-bond locations shall be not less than 167 percent of the length of the longest track circuit, any portion of which lies between the cross-bond points.
- Conversely, the total length of any track circuit, any portion of which is between the cross-bond points, shall not exceed 60 percent of the distance between the cross-bond points.
- The ideal arrangement shall be two equal length track circuits between cross-bond points, each 50 percent of the total distance between them.

Where the cross-bonds are up to a maximum of 6,000 feet apart:

- There shall be a minimum of 3 track circuits between the “A” and “B” point cross-bond locations.
- Distance between cross-bond locations shall be not less than 250 percent of the length of the longest track circuit, any portion of which lies between the cross-bond points.
- Conversely, the total length of any track circuit, any portion of which is between the cross-bond points, shall not exceed 40 percent of the distance between the cross-bond points.

- The ideal arrangement would be three equal length track circuits between cross-bond points, each 33.33 percent of the total distance between them. Total distance shall be as close to 6,000 feet as possible.
- In no case will a distance of less than 3,000 feet between "A" point cross-bond locations be permitted.

The "percent ratio" shall be calculated for any given section between cross-bond locations as D(XB) divided by D(LTC), where D(XB) is the distance between cross-bond points defining the section and D(LTC) is the length of the longest track circuit in the section.

Where "drain" bonds constitute an "A" point at other than insulated joint locations, the "D(LTC)" shall be the total length of the longest track circuit in the section including any portion of that track circuit outside the limits of the section defined by the cross-bond points.

22.7.3.2 Cross-bonding at Interlockings

Cross-bonding shall be placed as close to interlocking crossovers as practical to reduce the possibility of flashover of insulated joints in crossovers. If possible, an "A" point shall be placed at one of the interlocking home signal locations at each interlocking. This shall be done consistent with these design criteria and the need to place an "A" point at each substation, switching station or paralleling station return bus location.

Only one impedance bond shall be provided at the fouling insulated joints on the turnout track, located on the side of the joints away from the switch points. The neutral leads on this impedance bond shall be tied to the neutral leads between the impedance bonds located at the adjacent insulated joints on the main or straight track.

If there are no insulated joints on the main or straight track within approximately 20 feet of the fouling insulated joints on the turnout track, then a second impedance bond may be used on the turnout track at the fouling insulated joints, located on the switch point side of these joints and the neutral leads of the two impedance bonds at these joints connected in the usual manner. In this case, the neutral leads of the impedance bonds on the turnout track must <u>not</u> be connected to the neutral leads on the main or straight track.

22.7.3.3 Cross-bonding at Single and Twin Single Bore Tunnels

Where an "A" point is required within a single bore tunnel, the neutral leads of the impedance bonds shall be connected to the static wire in that tunnel only. Where an "A" point is required within twin single bore tunnels that incorporate cross passage(s) between bores, cross-bonding between bores shall be accomplished by laying the cables in the cross-passage(s).

22.7.3.4 Connections to Platform Grounding Systems

Counterpoises for at-grade station platforms shall be connected to the rail through the neutral leads of an impedance bond at one end of the platform only. The preference is to connect to the neutral leads of an "A" point. If it is not practicable to attach to an "A" point, the counterpoise shall be connected to the neutral leads of a "C" point. If this is not practicable, a drain bond

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shall be installed. Each platform shall have an independent counterpoise and impedance bond. The interconnection between the impedance bond neutral leads and the counterpoise conductor shall be an exothermic weld which shall be made in a handhole interface box.

Platforms located on aerial structures shall be grounded as identified above and shall be connected to the track through the neutral leads of an impedance bond at one end of the platform only, and with the same order of preference as detailed above. Each platform shall have an independent grounding system and impedance bond. If the impedance bonds used for this purpose are either “C” points or drain bonds, the location becomes a “B” point as the platform counterpoises on structures are attached to the structure and therefore both tracks will be connected together through the neutral leads of the impedance bonds.

22.8 Grounding and Bonding Protection Systems for the Communications System Equipment and Structures

22.8.1 General Requirements

Communications and electronic systems shall be grounded and bonded in accordance with the requirements specified in NFPA 70E, NFPA 75, ANSI/TIA/EIA-607, CEC, IEEE 1100 and ITU standards. The communications designer shall design a communications grounding system to have an impedance from device to ground per IEEE 1100.

The grounding methods for enclosures, chassis, panels, switch boxes, pull boxes, conduits, terminal boxes, and similar enclosures or structures shall be designed to provide proper terminations for equipment and cable shielding (as necessary) and to avoid conducted coupling, low impedance ground loops, noise, surges from adversely affecting system operation, and hazardous operating conditions—refer to the *Electromagnetic Compatibility and Interference* chapter for more details.

The ac grounding electrode system is the fundamental grounding element supporting the communications grounding system. The ac grounding electrode system design must be verified to provide a suitable ground resistance for all communications equipment it serves. The communications designer shall use the building structural steel as an additional bonding point for the communications grounding system. The impedance between the structural steel and the ac ground electrode system shall be compliant with IEEE Std. 142.

If the ac grounding electrode system does not supply compliant ground resistance, supplemental grounding electrodes shall be installed to lower ground resistance, and shall be connected to the ac grounding electrode system and the ground grid.

The communications grounding system serves to establish a common reference voltage for communications equipment cabinets, enclosures, equipment, and power supplies, and provide an intentional path for fault current to the ac grounding electrode system

The components that make up the communications grounding system include:

- Supplemental grounding electrodes
- Bonding conductor for communications
- Telecommunications Bonding Backbone (TBB)
- TBB Interconnecting Bonding Conductor (TBBIBC)
- Telecommunications Grounding Busbar (TGB)
- Rack Grounding Busbar (RGB)

Design documents shall clearly articulate details and connectivity of the communications grounding system.

The communications designer shall not design a separate communications-only or isolated ground system.

Bonding conductors shall be sized according to applicable standards and codes.

Bonding conductors run for distances less than 100 feet shall be minimum 6 AWG. For distances greater than 100 feet, the communications designer shall size bonding conductors using the more conservative requirements of either the NEC or the CEC.

22.8.2 Communication Equipment within Rooms at Stations and Facilities (located within a Shared Automatic Train Control and Communications Room and/or Dedicated Communications Room)

See Section 22.5 for ground grid requirements for buildings.

When communications equipment and ATC equipment occupy a shared room, the designer shall coordinate the equipment and shield grounding between the two disciplines.

22.8.2.1 Telecommunications Bonding Backbone within Stations and Facilities

Communications room grounding busbars shall be connected together by means of the telecommunications bonding backbone, which shall provide for the interconnection of the grounding busbars, located in each communications room or closet throughout the building, to the telecommunications main grounding busbar.

The telecommunications bonding backbone route and cable size shall be planned to minimize length and eliminate splices.

Wherever two or more vertical telecommunications bonding backbones are used in a building, the grounding busbars shall be interconnected at the top of each riser and at every third floor with a telecommunications bonding backbone interconnecting bonding conductor in accordance with ANSI/TIA/EIA-607 and the CEC and NEC.

22.8.2.2 Grounding Busbars within Communications Rooms within Stations and Facilities

A grounding busbar shall be provided in every communications room and within every shared ATC and communications room. An entrance facility shall be identified for each building where communications conduit and cable penetrates. The entrance facility shall be provided with a grounding busbar. The grounding busbar shall be located close to the ac ground electrode system. Where a panel board for telecommunications is located in the same room or space as the grounding busbar, that panel's ground bus or the enclosure shall be bonded to the grounding busbar.

In steel building structures, the telecommunications grounding busbar and telecommunications bonding backbone shall be bonded to the structural steel. The ground resistance between the structural steel and the ac grounding electrode system shall be compliant with IEEE Std. 142.

The communications grounding system in each room shall be bonded to the busbar in each communications room and communications closet. In communications rooms and closets, the busbar shall be bonded to the ac grounding electrode and the nearest structural steel member.

22.8.3 Communications Equipment and Structures

Provide a grounding busbar within all communications interface cabinets (CICs). Within CICs, the equipment grounding system shall bond equipment, rack rails, cabinets and cabinet doors to the telecommunications grounding busbar which shall be bonded to the incoming ac grounding electrode.

22.9 Grounding and Bonding Requirements for Facility Power Systems and Lighting Systems

See Section 22.5 for ground grid requirements.

A bare grounding electrode conductor shall be provided between the HV switchgear/transformer ground bus and the ground grid.

The secondary neutral of pad mounted medium and/or high voltage transformers shall be grounded. Additionally the pad design shall include the following features:

- Ground grid in accordance the CEC, or power utility service requirements as applicable.
- The concrete support pad reinforcement steel shall be bonded to the ground grid.

Exterior transformers supplying interior service equipment shall have the neutral grounded at the transformer secondary and a grounding electrode shall be provided at the transformer.

In the case of separately derived systems (i.e., transformers downstream from service equipment) ground the secondary neutral at the transformer to the nearest component of the grounding grid.

Lightning arresters on medium and high voltage equipment shall be connected to the equipment ground bus or ground rods as applicable.

For secondary switchgear, switchboards, and motor control centers, the following requirements shall apply:

- The equipment grounding conductors shall be connected to the ground bus in the enclosure with suitable pressure connectors.
- Metallic conduits, which terminate without mechanical connection to the housing, shall include grounding bushings and grounding conductor to the equipment ground bus.
- For service entrance equipment, the grounding electrode conductor, carried in the power supply conduit, shall be connected to the ground bus.

Ground the frames of motors larger than 25 hp by a ground conductor carried in power conduit.

Fixed electrical appliances and equipment shall be provided with a ground lug for termination of the equipment grounding conductor. Ground lugs shall be provided in each box and enclosure for equipment grounding conductor termination.

Panel boards shall contain a ground bus, bolted to the housing, with sufficient lugs to terminate the equipment grounding conductors.

Ground light fixtures to the equipment grounding conductor of the wiring system.

Receptacles shall not be grounded through their mounting screws. Ground with a jumper from the receptacle green ground terminal to the device box ground screw and the branch circuit equipment grounding conductor.

Feeder and branch ac power and lighting circuits shall have a separate insulated equipment grounding conductor.

Bond the equipment grounding conductor to each pullbox, junction box, outlet box, device box, cabinets, and other enclosures through which the conductor passes.

22.10 Grounding Requirements for Raceway, Cable Tray, Underground Ductbanks, and Structures

Metallic raceway and cable trays systems shall be bonded together to provide a continuous electrical ground path.

Metallic raceways shall be bonded to other raceway components using insulated grounding bushings. Grounding bushings shall be connected to the grounding system using conductors sized in compliance with the applicable code.

Connect each isolated metallic cable tray system or the entire cable tray system to the building grounding systems with a bare copper conductor in accordance with the CEC, NEC, and NEMA VE 1.

Provide an equipment ground conductor, sized in accordance with the CEC and NEC (but not less than 2 AWG for medium voltage power circuits) in each conduit of an underground ductbank that contains power cables.

Raceways for lighting and power feeders to motor, lighting, and receptacle loads shall contain a separate green insulated safety grounding conductor.

All normally-non-current-carrying conductive parts of manholes, handholes, pull boxes, splice boxes, metallic raceway, and/or cable tray systems shall be bonded and grounded. Provide at least one driven ground rod at each underground structure.

22.11 Cables

22.11.1 General

The metallic sheaths, armor or shields of power cables:

- Shall be electrically continuous through manholes, pull boxes, and splice boxes.
- Shall be designed and routed in accordance with the requirements detailed in the *Electromagnetic Compatibility and Interference* chapter.

Conductor splice case grounding and bonding requirements shall comply with the manufacturer's recommendations and CEC and NEC. It shall be ensured that the touch voltages at the non-grounded end of the metallic sheaths, armor or shields of cables do not exceed the maximum permissible touch voltages specified in Table 22-1.

22.11.2 Automatic Train Control System

Signal control or lighting cables and switch cables shall not have metallic shielding. Metallic messenger or duct shall not be used in any way that could cause an electrical interconnection between signals or signal structures and signal equipment housings.

22.11.3 Communications System

Bonding of shielded twisted-pair (STP) cables is necessary to mitigate the effects of unwanted noise signals (antenna effect) on communications cables and to avoid interference with overall network performance.

The shield of STP cables shall be bonded to the connecting hardware in accordance with the manufacturer's instructions. As appropriate, the connecting hardware at the cross-connect shall be bonded to the ground busbar in the ATC room or house, communications equipment shelter

or termination room, or communications room. Grounding at the work area is usually accomplished through the equipment power connection. Shield connections at the work area are accomplished through an STP patch cord. At the work area end of the horizontal cabling, the voltage measured between the shield and the ground wire of the electrical outlet used to supply power to the work station shall not exceed 1.0 V rms. Telephone and public address cables at ATC rooms or houses, communications shelters or termination rooms, and communications rooms that originate from the field devices, shall require surge protection.

Bond telephone protector units to the grounding system with at least a No. 6 AWG ground conductor.

22.11.4 Facility Power System and Lighting System

The shields of medium voltage ac power cables shall be grounded at the facility power electrical rooms and/or yards in accordance with the requirements detailed in the *Electromagnetic Compatibility and Interference* chapter. The shields shall be electrically continuous through manholes, pull boxes, and splice boxes.

The safety grounding conductors for feeder circuits shall each be bonded at one end to the electrical room or yard ground bus and at the other end to the ground bus of a panelboard or a motor control center ground bus. Each branch circuit shall have a safety-insulated grounding conductor extended from the ground bus of the panelboard or motor control center to the device it is serving.

22.11.5 Cable Trough and Outside Plant

Provide an equipment ground conductor, sized in accordance with the CEC (but not less than 2 AWG for medium voltage power circuits), in each conduit of an underground ductbank that contains power cables.

All normally non-current-carrying conductive parts of manholes, handholes, pull boxes, splice boxes, metallic raceway, and/or cable tray systems shall be bonded and grounded.

The communications designer shall coordinate with other disciplines and submit code compliant Outside Plant Cable (OSP) infrastructure bonding system.

22.12 Grounding and Bonding Requirements for Utilities

Non-railway pipes or cable shields should have no connection to the traction return and grounding systems. Metallic utility lines entering or passing through the Authority's right-of-way shall be fitted with insulated joints to separate the external services and isolate them from the traction return and grounding systems.

Pipes or shielded cables to or from non-railway installations may transfer potentials that could be bridged by persons as step or touch voltages. Additionally, corrosion may be caused by

potential differences, if different grounding systems are connected together. For these reasons non-railway grounding systems shall not be connected to railway systems.

Metallic sleeves or casings, installed to permit utility lines to cross the tracks (refer to the *Utilities* chapter) shall be grounded at one end only, with the grounding electrode having a resistance of 25 ohms or less.

Grounding and bonding for the electrical service shall be provided in accordance with the electric utility company's requirements.

Unless formally approved by the utility owner there shall be no connection between the grounding system and any utility (including water) outside the dielectric coupling which is used to isolate facilities from utilities outside the building line.

22.13 Lightning Protection

Each facility and exposed structure shall be provided with appropriate lightning protection measures, based on the incidence of strikes in the area local to each facility, which shall be grounded in accordance with the recommendations of the equipment manufacturer, CEC, NEC, NESC, GO 95, and NFPA 780 – Standard for the Installation of Lightning Protection Systems, as applicable.

Insulated cables carrying feeds to the OCS shall be protected with surge arresters.

The OCS designer shall investigate the incidence of lightning storms on a project section-by-section basis and shall determine appropriate lightning protection measures, based upon the incidence of lightning strikes in each area. Where lightning protection of the OCS is deemed necessary, a shield wire shall be installed at the top of the OCS poles, which may necessitate an increase in pole height to achieve the required clearances. If the cone of protection afforded from this position is insufficient, the shield wire shall be mounted on an outrigger cantilever so that shield wire is more closely positioned above and affords protection for all of the OCS conductors. The shield wire shall be insulated from the OCS poles in passenger station areas. Additional protection/mitigation measures, e.g., additional grounding conductors/grids, shall be provided as required.

Lightning arresters and other circuit protection devices shall be provided as necessary to protect wayside ATC equipment from damage and false operation due to lightning. The lightning arresters shall comply with AREMA Signal Manual, for lightning protection.

Trackside antenna towers (e.g. at ATC houses, communication equipment shelters, TPF, etc.) within the Authority's right-of-way are specified to be 100 feet tall. Appropriate lightning protection measures shall be provided based on the incidence of strikes in the area local to each antenna tower and/or roof mounted antenna.

Reinforced concrete structures may not be able to take direct lightning strikes without damage. Exposed prestressed concrete structures shall be provided with lightning protection, especially in lightning prone areas.

The electrodes—ground rods or ground grids—used to ground lightning protection systems shall not be the same as those used for grounding of either the traction or facility electrical systems, but the electrodes from both systems must be bonded together.

Chapter 23

Corrosion Control

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Revision	Date	Description
0	02 Mar 12	Initial Release, R0

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Acronyms

See Section 23.2 - Regulations, Codes, and Standards for Acronyms used in this chapter

23 Corrosion Control

23.1 Scope

This chapter describes the requirements for a corrosion control system design which shall prevent premature corrosion failure, and be economical to install, operate, and maintain. Corrosion control provisions shall be required for all facilities, regardless of location or material of construction subject to corrosion, where failure would affect safety or interrupt continuity of operations.

Two major types of corrosion control shall be implemented: soil and water corrosion control, and atmospheric corrosion control.

The design criteria for each of these categories, and their implementation, shall meet the design life of structures and systems listed in the *General* chapter:

- Minimize annual operating and maintenance costs associated with material deterioration.
- Provide continuity of operations by reducing or eliminating corrosion related failures.

23.2 Regulations, Codes, Standards, and Guidelines

Refer to the *General* chapter for requirements pertaining to regulations, codes, and standards.

- American Concrete Institute (ACI)
- American National Standards Institute (ANSI)
- American Railway Engineering and Maintenance-of-Way Association (AREMA)
- American Society of Mechanical Engineers (ASME)
- American Society of Testing and Materials International (ASTM)
- American Water Works Association (AWWA)
- California Department of Transportation (Caltrans)
- Concrete Reinforcing Steel Institute (CRSI)
- Electronic Industries Association (EIA)
- Environmental Protection Agency (EPA)
- European Standards (EN for European Norms)
- Insulated Cable Engineers Associated (ICEA)
- International Electrotechnical Commission (IEC)

- Illuminating Engineering Society of North America (IESNA)
- Institute of Electrical and Electronics Engineers (IEEE)
- International Organization for Standardization (ISO)
- National Association of Corrosion Engineers International (NACE)
- National Electrical Manufacturers Association (NEMA)
- National Fire Protection Association (NFPA)
- Occupational Safety and Health Administration (OSHA)
- State of California Codes and Code of Regulations
- Steel Structures Painting Council (SSPC)
- Underwriters' Laboratories (UL)

23.3 Soil and Water Corrosion Control

23.3.1 General

The goal of this design is to prevent corrosion of structures due to soil and water. Soil and ground water characteristics shall be determined and documented through boring surveys. Analysis of the data obtained from on-site borings shall be the basis for corrosion control designs. The soil/water samples shall be analyzed for resistivity (or conductivity), pH, chloride and sulfate ion concentrations (Refer to the *Geotechnical* chapter). Corrosion survey on site, testing soil resistivity, pH, redox potential, and stray current presence shall supplement water/soil samples laboratory analysis.

Normally, affected structures, as in the conditions listed below, shall be protected against the environment by coating, insulation, electrical continuity and/or cathodic protection, whichever is applicable. Water treatment shall be considered to mitigate chemical and microbiologically influenced corrosion inside of pipes and water tanks. Special attention shall be taken to prevent salt water corrosion on underground metallic structures.

Structures which may be affected by soil and water corrosion typically include, but are not limited to:

- Buried and on-grade reinforced concrete structures
- Pier and piling structures
- Concrete tunnel liner
- Ferrous piping (gas, water, sewage, casings etc.)
- Underground storage tanks
- Electrical conduits

- Copper piping
- Metallic fencing

23.3.1.1 Materials of Construction

All pressure and non-pressure piping and conduit shall be non-metallic, unless metallic materials are required for specific engineering purposes.

Aluminum and aluminum alloys shall not be used in direct burial applications.

If non-native fill is to be used for backfilling concrete or ferrous structures, then it shall meet the following criteria:

- pH 6 to 8
- Maximum chloride ion concentration of 250 ppm
- Maximum sulfate ion concentration of 200 ppm

Methods to control corrosion of reinforced concrete structures are primarily directed toward preventing or impeding ingress of water and chloride ions into concrete and/or protecting steel rebar after chloride contamination occurs. Based on ACI guidelines, methods in use are the following:

- Control of the concrete mix to obtain low permeable concrete
- Limit chlorides in the original concrete mix ingredients
- Use an inhibitor in the concrete mix
- Increase concrete cover to reinforcement
- Use concrete sealers and coatings
- Use epoxy coated reinforcement
- Apply cathodic protection

23.3.1.2 Safety and Continuity of Operations

Corrosion control protection shall be required for those facilities where failure caused by corrosion of such facilities may affect the safety, or interrupt the continuity of operations.

23.3.1.3 Accessibility of Installations

Where required, permanent test facilities installed with certain corrosion control provisions shall be accessible after installation, allowing for periodic maintenance and monitoring.

23.3.2 Coating

Coatings specified for corrosion control of buried metallic or concrete facilities shall satisfy the following criteria:

- Minimum volume resistivity of 10,000,000,000 ohm-centimeters (10 billion ohm-centimeters)
- Minimum thickness as recommended for the specific system, but not less than 15 mils
- A chemical or mechanical bond to the metal or concrete surface. Pressure-sensitive systems are not acceptable.
- Minimum 5-year performance record for the intended service
- Mill application wherever possible, with field application of a compatible paint or tape system
- Mechanical characteristics capable of withstanding coating damage during handling and earth pressure after installation for the design life of the system

23.3.2.1 Generic Coating Systems

Generic coating systems include but are not limited to the following:

- Extruded polyethylene/butyl based system
- Coal-tar epoxies (two component systems)
- Polyethylene-backed butyl mastic tapes (cold applied)
- Bituminous mastics (airless spray)

23.3.3 Electrical Insulation of Piping

Devices used for electrical insulators for corrosion control shall include non-metallic inserts, insulating flanges, couplings, unions, and/or concentric support spacers. Devices shall meet the following criteria:

- A minimum resistance of 10 megohms prior to installation.
- Sufficient electrical resistance after insertion into the operating piping system such that no more than 2 percent of a test current applied across the device flows through the insulator, including flow through conductive fluids if present.
- Mechanical and temperature ratings equivalent to the structure in which they are installed.
- Internal coating (except complete non-metallic units) with a polyamide epoxy for a distance on each side of the insulator equal to two times the diameter of the pipe in which they are used. Where conductive fluids with a resistivity of less than 2,000 ohm-centimeters are present, internal coating requirements shall be based on separate evaluation.
- Devices (except non-metallic units) buried in soils shall be encased in a protective coating.
- Devices (except non-metallic units) installed in chambers or otherwise exposed to partial immersion or high humidity shall have a protective coating applied over all components.
- Inaccessible insulating devices, such as buried or elevated insulators, shall be equipped with accessible permanent test facilities.

- A minimum clearance of 12 inches shall be provided between new and existing metallic structures. When conditions do not allow a 12-inch clearance, the design shall include special provisions to prevent electrical contact with existing structure(s).

23.3.4 Electrical Continuity of Metallic Structures

Electrical continuity shall be provided for all non-welded metallic joints and shall meet the following criteria:

- Use direct burial, insulated, stranded, copper wire with the minimum length necessary to span the joint being bonded.
- Wire size shall be based on the electrical characteristics of the structure and resulting electrical network to minimize attenuation and allow for cathodic protection.
- Use a minimum of two wires per joint for redundancy.

23.3.5 Cathodic Protection

Cathodic protection shall be accomplished by sacrificial galvanic anodes to minimize corrosion interaction with other underground utilities. Impressed current systems shall be used only when the use of sacrificial systems is not technically and/or economically feasible.

Cathodic protection system design shall be based on theoretical calculations that include the following parameters:

- Estimated percentage of bare surface area (minimum 1 percent)
- Cathodic protection current density (minimum of 1.0 mA/ft^2 of bare surface area)
- Estimated current output per anode
- Estimated total number of anodes, size, and spacing
- Minimum anode life of 25 years (minimum 50 percent efficiency)
- Estimated anode groundbed resistance

Impressed current rectifier systems shall be designed using variable voltage and current output rectifiers. Rectifiers shall be rated at a minimum of 50 percent above calculated operating levels to overcome a higher-than-anticipated anode groundbed resistance, lower-than-anticipated coating resistance, or presence of interference mitigation bonds. Other conditions which may result in increased voltage and current requirements shall be considered.

Test facilities consisting of a minimum of two structure connections, one reference electrode connection, conduits and termination boxes shall be designed to permit initial and periodic testing of cathodic protection levels, interference currents, and system components (anodes, insulating devices, and continuity bonds). By request of the particular utility owner/operator

remotely monitored test facilities could be designed. The designer shall specify the locations and types of test facilities for each cathodic protection system.

23.3.6 Ferrous Pressure Piping

All new buried cast iron, ductile iron, and steel pressure piping shall be cathodically protected. System design shall satisfy the following minimum criteria:

- Application of a protective coating to the external surface of the pipe (see Section 23.3.2).
- Electrical insulation of pipe from interconnecting pipe, other structures and segregation into discrete electrically isolated sections depending upon the total length of piping (see Section 23.3.3).
- Electrical continuity through the installation of copper wires across all mechanical pipe joints other than intended insulators (see Section 23.3.4).
- Permanent test/access facilities to allow for verification of electrical continuity, electrical effectiveness of insulators and coating, and evaluation of cathodic protection levels, installed at all insulated connections. Additional test/access facilities shall be installed at intermediate locations, either at intervals not greater than 200 feet, or at greater intervals determined on an individual structure basis.
- Number and location of anodes and size of rectifier (if required) shall be determined on an individual structure basis.

23.3.7 Copper Piping

Buried copper pipe shall be electrically isolated from non-buried piping, such as that contained in a station structure, through use of an accessible insulating union installed where the piping enters through a wall or floor. Pipe penetrations through the walls and floors shall be electrically isolated from building structural elements. The insulator shall be located inside the structure and not buried.

23.3.8 Gravity Flow Piping (Non-Pressured)

23.3.8.1 Corrugated Steel Piping

Corrugated steel piping shall be internally and externally coated with a sacrificial metallic coating and a protective organic coating.

23.3.8.2 Cast or Ductile Iron Piping

Cast or ductile iron piping shall be designed and fabricated to include the following provisions:

- An internal mortar lining with a bituminous coating on ductile iron pipe only (not required for cast iron soil pipe)

- A bonded protective coating or unbonded dielectric encasement on the external surfaces in contact with soils (AWWA Standard C105)
- A bituminous mastic coating on the external surfaces of pipe 6 inches on each side of a concrete/soil interface

23.3.8.3 Reinforced Concrete Non-Pressure Piping

Reinforced concrete non-pressure piping shall include the following provisions:

- Water/cement ratios meeting the minimum provisions of AWWA
- Maximum 250 ppm chloride concentration in the total concrete mix (mixing water, cement, admixture and aggregates)

23.3.8.4 Electrical Conduits

Buried metallic conduits shall include the following provisions:

- Galvanized steel with PVC or other coating acceptable for direct burial, including couplings and fittings. The PVC coating is not required when conduits are installed in concrete.
- Electrical continuity through use of standard threaded joints or bond wires installed across non-threaded joints.

23.3.8.5 Utility Structures

All piping and conduit shall be non-metallic, unless metallic facilities are required for specific engineering purposes. There are no special provisions required if non-metallic materials are used.

23.3.8.6 Metallic Facilities (System-wide)

Pressure or non-pressure piping exposed within tunnels or crawl spaces or embedded in concrete inverts shall not require special provisions.

Pressure piping that penetrates tunnel, foundation, or tunnel walls shall be electrically insulated from the external piping to which it connects and from watertight wall sleeves. Electrical insulation of interior piping from external piping shall be made on the inside of the tunnel.

Pressure piping running on the top of the bridge or aerial structure shall be electrically isolated from the underground portion of the piping.

All buried pressurized piping shall meet the criteria specified in Section 23.3.6.

23.4 Atmospheric Corrosion Control

Alternating wet and dry weather together with industrial and chemical pollutants can contribute to increased corrosion rates of exposed metal structures and hardware. The atmospheric corrosion conditions shall be derived from different existing sources. Designs and

associated coatings shall be based on recommendations of the reports and shall be used to significantly decrease atmospheric corrosion rates.

The purpose of these criteria is to insure the function, preservation and appearance of project structures exposed to the environment in the most cost effective manner. Criteria include the following:

- **Materials selection** – acceptable materials shall have proven past performance records for the service application.
- **Protective coatings** – barrier or sacrificial coatings shall be used on steel.
- **Design** –recess moisture traps and dissimilar metals shall be avoided.
- **Sealants** – accumulation of moisture in crevices shall be prevented by use of sealants.

23.4.1 Scope

Exposed metal surfaces on aerial and tunnel structures affected by atmospheric corrosion shall be coated. Marine atmosphere shall be considered along the track alignment to develop coating systems. Coating for the catenary poles shall be developed based on local atmospheric conditions.

Coatings shall have established performance records for the intended service and be compatible with the base metal to which they are applied.

Coatings shall be able to demonstrate satisfactory gloss retention, color retention, and resistance to chalking over their minimum life expectancies.

Coatings shall have minimum life expectancies, defined as the time prior to major maintenance or reapplication, of 15 to 20 years.

23.4.2 Metallic-Sacrificial Coatings

Acceptable coatings for carbon and alloy steels for use in tunnels, crawlspaces, vaults, or above grade are as follows:

- Zinc (hot-dip galvanizing [2 ounces per square feet] or flame sprayed)
- Aluminum (hot-dip galvanizing [2 mil thickness] or flame sprayed)
- Aluminum-zinc
- Inorganic or organic zinc (as a primer)

23.4.3 Organic Coatings

Organic coating systems shall consist of a wash primer (for galvanized and aluminum substrates only), a primer, intermediate coat(s), and a finish coat. Acceptable organic coatings, for exposure to the atmosphere, are as follows:

- Aliphatic polyurethanes
- Vinyl copolymers
- Fusion-bonded epoxy polyesters, polyethylenes, and nylons
- Acrylics, where not exposed to direct sunlight
- Alkyds, where not exposed to direct sunlight
- Epoxy as a primer where exposed to the atmosphere or as the complete system where sheltered from sunlight

23.4.4 Barrier Coating System

Use one of the following barrier coating systems where corrosion protection is needed but appearance is not a primary concern:

- Near white blast surface according to SSPC-SP 10. Follow with a 3-coat epoxy system
- Commercial blast surface according to SSPC-SP 6. Follow with a 2-coat inorganic zinc and high build epoxy system
- Near white blast surface according to SSPC-SP 10. Follow with a 3-coat epoxy zinc, high build epoxy system
- Apply all coatings according to manufacturer's specifications

Use one of the following barrier coating systems where corrosion protection and good appearance are needed.

- Near white blast surface according to SSPC-SP 10. Follow with a 3-coat inorganic zinc, high build epoxy, polyester urethane system.
- Near white blast surface according to SSPC-SP 10. Follow with a 3-coat vinyl system.
- Commercial blast surface according to SSPC-SP 6. Follow with a 3-coat epoxy zinc, high build epoxy and polyester urethane system.
- Commercial blast surface according to SSPC-SP 6. Follow with a 3-coat epoxy zinc, high build epoxy and acrylic urethane system.
- Apply all coating according to manufacturer's specifications.

23.4.5 Graffiti-Resistant Coatings

Surfaces which are accessible to graffiti shall be protected with a graffiti-resistant coating. This includes concrete and painted steel surfaces such as walls, columns, and equipment enclosures. All such areas shall be protected up to a height of 10 feet. The coating shall be a urethane-type coating and shall be applied in accordance with the manufacturer’s latest published instructions.

23.5 Stray Current Sources and Protection

Dc powered transit systems like BART, LA Metro, VTA, and LRT in San Diego could be a source of stray currents for metallic and concrete underground facilities. Welding operations in the industrial areas could be another source of stray currents. Stray current corrosion survey in the vicinity of dc-powered transit lines and in industrial portions of project proposed track alignment shall identify areas with the stray current activity. Local utility companies shall be contacted to obtain information regarding their practice of stray current protection in areas where dc stray currents are present.

Corrosion control requirements for buried utilities installed by the utility owner/operator as part of high-speed train construction shall be the responsibility of the individual utility owner/operator. Relocated or replaced utilities, installed by high-speed train contractors as part of contractual agreement between the Authority and the utility, shall be installed in accordance with the utility owner specifications and shall include the following minimum provisions:

- Electrical continuity through the installation of insulated copper wires across all mechanical joints for which electrical continuity cannot be assured
- Electrical access to the utility structure via test facilities installed at nominal 200 feet intervals

These provisions are applicable to ferrous and reinforced concrete cylinder piping. Other materials and structures will require individual review.

The need for additional measures, such as electrical isolation, application of a protective coating system, installation of cathodic protection, or any combination of the preceding, shall be based on the characteristics of the specific structure and shall not adversely affect the existing performance within the environment.

In the areas with stray current presence in the vicinity of high-speed train tracks, test stations shall be installed to monitor rail-to-ground voltages.

Chapter 24

Automatic Train Control

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Revision	Date	Description
0	02 Mar 12	Initial Release, R0

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Acronyms

AREMA C&S	American Railway Engineering and Maintenance-of-Way Association Communications & Signals
ATC	Automatic Train Control
ATO	Automatic Train Operation
ATP	Automatic Train Protection
ATS	Automatic Train Supervision
CFR	Code of Federal Regulations
EMU	Electric Multiple Unit
ERA	European Railway Agency
ERTMS	European Rail Traffic Management System
FFFIS	Form Fit Function Interface Specification
FMEA	Failure Mode and Effect Analysis
HMI	Human Machine Interface
ID	identification
IEEE	Institute of Electrical and Electronics Engineers
MA	Movement Authority
MOI	Maintenance of Infrastructure
MTBF	Mean Time Between Failures
MTTR	Mean Time to Restore
MTTT	Mean Time To Travel
OCC	Operation Control Center
OCS	Overhead Contact System
OEM	Original Equipment Manufacturer
POSIX	Portable Operating System Interface
PTC	Positive Train Control
RBC	Radio Block Centers
RAM	Reliability, Availability, Maintainability
RAMS	Reliability, Availability, Maintainability, and Safety
RCC	Regional Control Center
RS	Rolling Stock
SBD	Safe Braking Design
SCADA	Supervisory Control and Data Acquisition
SIL	Safety Integrity Level
UNISIG	Union Industry of Signalling (UNISIG)

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24 Automatic Train Control

24.1 Scope

The Automatic Train Control (ATC) system and its subsystems shall meet the requirements of the standard specifications and preliminary engineering drawings and all applicable regulatory and interoperability requirements. The ATC system shall meet all of the applicable portions of the Code of Federal Regulations (CFR): 49 CFR 236 except as modified by the FRA Guideline documents. The ATC system shall meet all applicable requirements of all modifications to the CFR. The ATC system shall provide all specified functions and shall consist of the equipment required to provide safety-critical Automatic Train Protection (ATP), Automatic Train Operation, (ATO), and Automatic Train Supervision (ATS) functions.

24.2 Regulations, Codes, Standards, and Guidelines

Refer to the *General* chapter for requirements pertaining to regulations, codes, and standards.

- Code of Federal Regulations (CFR); Title 49 CFR, Parts 229, 233 and 236
- American Railway Engineering and Maintenance-of-Way Association Communications & Signals (AREMA C&S) Manual of Recommended Practices
  - Part 17 – Recommended
- U.S. Department of Defense (USDOD) Standards
  - MIL-HDBK-217F – Military handbook – Reliability Prediction of Electronic Equipment
  - MIL-STD-785B – Reliability Program for System and Equipment Development and Production
  - MIL-STD-756B – Reliability Modeling and Prediction
  - MIL-STD-1629A – Procedures for Performing a Failure Mode, Effects and Criticality Analysis
- European Committee for Electrotechnical Standardization (CENELEC) Standards
  - EN 50121-4 – Railway applications – Electromagnetic compatibility Part 4: Emission and immunity of the signalling and telecommunications apparatus
  - EN 50125-1 – Railway applications – Environmental conditions for equipment – Part 1: Equipment onboard rolling stock
  - EN 50125-3 – Railway applications – Environmental conditions for equipment – Part 3: Equipment for signalling and telecommunications

- EN 50126-1 – Railway applications – The specification and demonstration of Reliability, Availability, Maintainability and Safety – Part 1: Basic requirements and generic process (1999)
- CLC/TR 50126-2 Railway applications – The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS) – Part 2: Guide to the application of EN 50126-1 for safety (2007)
- EN 50128 – Railway applications – Communications, signalling and processing systems – Software for railway control and protection systems (2011)
- EN 50129 – Railway applications – Communications, signalling and processing systems – Safety related electronic systems for signalling (2003)
- EN 50159 – Railway applications – Communications, signalling and processing systems : Safety-related communication in transmission systems (2010)

- International Electrotechnical Commission (IEC) Standards
  - IEC 60812 – Analysis techniques for system reliability – Procedures for failure mode and effect analysis (FMEA)
- Institute of Electrical and Electronics Engineers (IEEE) Standards
  - IEEE 828-2005 - IEEE Standard for Software Configuration Management Plans.
  - IEEE 1558 – IEEE Standard for Software Documentation for Rail Equipment and Systems
  - ANSI/IEEE 1028 – IEEE Standard for Software Reviews – The Institute of Electrical and Electronics Engineers
  - IEEE 1003 – IEEE Standard for Information Technology - Portable Operating System Interface (POSIX)
  - IEEE 1008 – IEEE Standard for Software Unit Testing
  - IEEE 1228 – IEEE Standard for Software Safety Plans
  - IEEE 1698 – IEEE Guide for the Calculation of Braking Distances for Rail Transit Vehicles (2009)
- European Railway Agency (ERA)/ Union Industry of Signalling (UNISIG) Specifications
  - ERA/UNISIG Subset 036 – FFFIS for Eurobalise
  - ERA/UNISIG SUBSET 036 – Form Fit Function Interface Specification (FFFIS) for Eurobalise
  - ERA/UNISIG Subset 037 – Euro Radio Functional Interface Specification (FIS)
  - ERA/UNISIG SUBSET 039 – Functional Interface Specification for the RBC/RBC Handover

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  - ERA/UNISIG SUBSET 040 – Dimensioning and Engineering Rules
  - ERA/UNISIG Subset 047 – Trackside-Train borne FIS
  - ERA/UNISIG Subset 085 – Test specification for Eurobalise FFFIS
  - ERA/UNISIG Subset 092-1 – ERTMS Euro Radio Conformance Requirements
  - ERA/UNISIG Subset 092-2 – ERTMS Euro Radio Test cases Safety Layer
  - ERA/UNISIG SUBSET 097 – Requirements for RBC-RBC Safe Communications Interface
  - ERA/UNISIG SUBSET 098 – RBC-RBC Safe Communication Interface
  - ERA/UNISIG SUBSET 099 – Test Specification for Safe Communication Interface
  - ERA/UNISIG SUBSET A11T6001-12 – MORANE Radio Transmission FFFIS for Euro Radio
  - EEIG 96S126 – ERTMS/ETCS RAMS Requirements Specification
- International Union of Railways (UIC) Codes
  - UIC 612 – 0 - Driver Machine Interfaces for EMU/DMU, Locomotives, and Driving Coaches – Functional and system requirements associated with harmonized Driver Machine Interfaces

24.3 General Design Requirements

The signaling and train control system shall be collectively known as the ATC system. ATC includes all the safety critical and non-safety critical functions of a train control system, and includes all Positive Train Control (PTC) functions.

Functionality of the ATC system shall include the following:

- Route setting and locking by means of interlocking functions.
  - PTC functions enforcing speed limits, prevention of collisions between trains, compliance with route limits, and prevention of intrusion into work zones
  - Integrating with track-side signaling equipment including interlockings, wayside signals, and, track circuits
  - Interfacing to the Overhead Contact System (OCS) for the provision of electrical power to interlocking and other ATC facilities and equipment
  - Interfacing to the communications systems including radio and network to communicate between the ATC subsystems including wayside, central, and onboard
  - Integrating to Rolling Stock (RS) defect detectors (where provided) mounted at the wayside including hot axle bearings, dragging equipment, and high/wide load

  - Interfacing to onboard defect, event, and incident detectors including hot axle bearings
  - Interfacing to wayside defect, event, and incident detectors (where provided) including, landslides, seismic activity, intrusion, excessive wind speed, flood, excessive rain, etc.
  - Communication with customer information systems including passenger information and public address systems providing real time train identification (ID) and schedule adherence data
  - Locating trains with sufficient accuracy and reliability so as to meet safety, reliability and operational performance criteria
- Onboard — Enforcing Movement Authorities (MAs) including track description, speed limits (permanent and temporary), and implementing other commands assigned to specific trains
- Providing secure and efficient communications paths between the ATC wayside and onboard subsystems for the following information:
  - Wayside Transponder (Eurobalise or similar) transmission to the train.
  - Communicating safety critical information to trains from the wayside ATC subsystem, by radio or by coded track circuit, including MAs and temporary and permanent database updates
  - Communicating non-safety critical information to trains from the wayside ATC zone controller, by radio
  - Communicating from trains to the ATS subsystem to facilitate route setting and other supervision functions, alarm and event notification, schedule regulation, and subsystem maintenance functions

Refer to the *Communications* chapter for the data communications design requirements including network and radio.

The design of the ATC system shall provide for ease of maintenance including easy access to all equipment and effective diagnostics provided for maintainers at the local equipment and at remote locations.

All enclosures and the equipment mounted within them, equipment mounted in rooms provided by others, and equipment mounted along the Authority's right-of-way shall be designed in accordance with the seismic considerations as defined in the *Seismic* chapter of these Design Criteria.

The secure mounting of enclosures and equipment along the ROW shall be accomplished in accordance with the *Structures* chapter of these Design Criteria.

Final site preparation shall be designed to be compatible with the requirements for placing foundations for enclosures including houses and cases and for using the compound as a working site and in accordance with the *Civil* chapter of these design criteria.

These criteria allow either a radio-based or a coded track circuit-based ATC system.

If the Designer proposes an ERTMS Level 2 system, the air gap interfaces shall meet the following requirements:

- ERA/UNISIG Subset 037 – Euro Radio Functional Interface Specification (FIS)
- ERA/UNISIG Subset 047 – Trackside-Train borne FIS
- ERA/UNISIG Subset 092-1 – ERTMS Euro Radio Conformance Requirements
- ERA/UNISIG Subset 092-2 – ERTMS Euro Radio Test cases Safety Layer
- ERA/UNISIG SUBSET A11T6001-12 – MORANE Radio Transmission FFFIS for Euro Radio

Where Eurobalises are deployed, the air gap interfaces shall meet the following requirements:

- ERA/UNISIG Subset 036 – FFFIS for Eurobalise
- ERA/UNISIG Subset 085 – Test specification for Eurobalise FFFIS

Spare capacity; provision for spare capacity (scalability) shall be designed into all enclosure spaces, cable conductors (copper and fiber), and network and data communication channels.

24.3.1 Design Speeds

See the *General* chapter for the maximum design and operating speeds.

24.3.2 Design Life

The ATC subsystems shall have useful lives as defined in the *General* chapter of these Design Criteria.

24.3.3 Headway

The design headway shall be 3 minutes between trains at maximum civil speed limits (based on passenger comfort speed limits).

24.3.4 Product Selection

Equipment and products (including software) shall have been proven in high-speed passenger rail service (at operating speeds consistent with the design objectives) for 5 years and shall be demonstrated to meet the Reliability, Availability, Maintainability, and Safety (RAMS) requirements in a similar high-speed rail application and in the range of climates similar to the California environment.

24.3.5 Uniformity

Equipment and products including firmware and software shall be uniform throughout the project subject to procurement strategies and contract limits so as to simplify maintenance procedures and to minimize the spare and replacement parts holdings across the project to the greatest extent practical.

24.3.6 Environmental Conditions

The climatic and physical environmental specifications and performance of ATC equipment installed at the wayside shall comply with AREMA C&S Manual of Recommended Practices and the relevant portions of EN 50125-3 – Railway applications – Environmental conditions for equipment – Part 3: Equipment for signaling and telecommunications. In the event that these requirements are in conflict, the more arduous and restrictive conditions shall apply.

The climatic and physical environmental specifications and performance of ATC equipment installed onboard passenger trains shall comply with the criteria defined in the rolling stock specification “Section 4: Climate and Environment”.

ATC equipment installed on works trains shall comply with EN 50125-1 – Railway applications – Environmental conditions for equipment – Part 1: Equipment onboard rolling stock.

For other climatic conditions refer to the *General* chapter of these Design Criteria.

24.3.7 Electromagnetic Compatibility

ATC equipment shall not interfere with or be interfered with by other equipment or equipment external to the Project. The ATC system design shall comply with the requirements of the *Electromagnetic Compatibility and Interference* chapter of these Design Criteria.

24.3.8 Reliability, Availability, and Maintainability

The reliability of the ATC and its subsystems shall be consistent with the overall Reliability, Availability, and Maintainability (RAM) requirements. RAMS requirements shall be in accordance with EN 50126-1 Railway Applications – The specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS). Other standards will be considered on the condition that the Designer provides a comprehensive equivalency report that maps the correlation between EN 50126-1 and their proposed standard(s).

ATC availability shall also be consistent with the availability requirements of the overall project high level thresholds. ATC system availability shall be higher than 99.99 percent. Failures shall be identified as Immobilizing, Service, and Minor; these terms are defined as follows:

- **Immobilizing Failure** — An Immobilizing Failure is one which occurs in the ATC System and fulfils any of the following:

- It causes or could cause more than one train to be delayed longer than the threshold delay time.
- It causes more than one train to run in a more restrictive operating mode than would have otherwise been the case in its absence.

- **Service Failure** — A Service Failure is one which occurs in the ATC System, is caused by the ATC System, and fulfils any of the following:
  - It causes or could cause one train to be delayed longer than the threshold delay time.
  - It causes one train to run in a more restrictive operating mode than would have otherwise been the case in its absence.
- **Minor Failure** — A Minor Failure is one which occurs in the ATC System and is neither an Immobilizing Failure nor a Service Failure.

For assessment of the RAM quantified specifications, the Target System shall be defined as one ATC equipped and supervised train plus all of the ATC System wayside and office equipment of the most complex track section encountered during a 1 hour trip at the speed of 220 miles per hour (mph).

The most complex track section is that part of the line which has the highest density of the ATC System elements.

The following conditions may be taken as a reference for the most complex (the worst case) application on the Target System:

• Trip duration	1 hour
• Train speed	220 mph
• Transponder messages	366
• Radio messages	850
• Number of Radio Block Centers (RBCs)	5
• Number of switches	72
• Number of interlockings	20
• Number of transponder locations	367
• Number of transponders per location	2

The ATC Target System shall achieve the following Mean Time Between Failures (MTBF) quantitative requirements:

• MTBF for Immobilizing Failures:	$MTBF_{Im} \geq 120000$ h
• MTBF for Service Failures:	$MTBF_{Se} \geq 14000$ h

- MTBF for Minor Failures: $MTBF_{Mi} \geq$ 480 h

The Designer shall extrapolate all reliability calculations for the system under contract and demonstrate that it shall achieve in service achieve the extrapolated reliability requirements.

Human factors contributions to RAM shall be considered as follows:

- Mean Time To Travel (MTTT) shall be a fixed value selected by the Authority, based on experience from other high-speed rail operators, reflecting the location of Maintenance of Infrastructure (MOI) facilities and highway access to ATC wayside locations.
- The supplier shall demonstrate that a Mean Time to Restore (MTTR) of 30 minutes is achievable. MTTR is a mean value for all ATC Line Replaceable Units; it includes diagnosis of faults measured from the actual start of work on site, replacing of faulty components, testing, and placing the system back into service in the affected area. MTTR does not include MTTT.

24.3.9 Safety Critical System Requirements

The ATC system shall meet all safety requirements of 49 CFR 236, except as modified by the FRA Guideline documents..

Safety shall be demonstrated in accordance with EN 50126-1 – Railway Applications – The specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS); Part 1: Basic requirements and generic process.

Other standards will be considered on the condition that the Designer provides a comprehensive equivalency report that maps between EN 50126-1 and other specified standards and their proposed standard(s).

The related application guide CLC/TR 50126-2 Railway applications – The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS) – Part 2: Guide to the application of EN 50126-1 for safety (2007) shall also apply.

The design, construction, installation, acceptance, operation, maintenance, and modification/extension of the ATC system, including the development of hazard mitigation procedures and other means, shall provide a quantitative level of safety such that any single, independent hardware, software or communication failure, or any combination of such failures with the potential of causing death or severe injury to passengers or staff, shall not occur with a frequency greater than once per 10^9 system operating hours. This shall be documented and certified to Safety Integrity Level (SIL) 4 in accordance with the following:

- EN 50126 – Part 1, Railway applications – The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS) – Part 1: Basic requirements and generic process (1999)

- EN 50128 – Railway applications – Communications, signalling and processing systems. Software for railway control and protection system (2011)
- EN 50129 – Railway applications – Communication, signalling and processing systems. Safety related electronic systems for signaling (2003)
- EN 50159 – Railway applications – Communication, signalling and processing systems – Safety–related communication in transmission systems (2010)

Tolerable Hazard Rates attributed to operations and maintenance actions shall be considered to be zero for the purpose of the ATC safety calculations.

24.3.10 Safe Braking

The ATC system shall implement a Safe Braking Design (SBD) for each type of train that can operate on the system that is equipped with an onboard ATC subsystem and is subject to ATC enforcement. The SBD shall be the set of design provisions and procedures which together ensure that a train's ATP safe stopping distance is safe in normal situations and in all likely combinations of adverse factors and failure conditions. The ATC SBD shall cover passenger trains consisting of one or two coupled Electric Multiple Unit (EMU) trainsets, and work trains of variable consists that are equipped with ATC. Non-ATC-equipped work trains and failed-equipped trains shall operate under rules and procedures and in compliance with wayside signal aspects to mitigate hazards. The wayside signal design shall be compatible with the SBD for manually operated unequipped and failed trains.

The ATC system requires guaranteed train braking performance that includes an Assured Emergency Brake Rate (AEBR).with a specified level of worst case wheel-rail adhesion. The Rolling stock specification "Section 11: Braking" defines the minimum braking performance levels. Coordination is required with RS engineering to confirm the braking performance of passenger vehicles including brake rates, build up times, variation in rate application versus time and train speed, spin-slide control parameters, and an agreed level of degradation of braking effort due to failure(s) within the braking system.

MOI Engineering shall confirm the braking performance of maintenance (non-passenger) rolling stock including the same values for passenger rolling stock as described earlier in this section.

Guaranteed braking performance shall be determined for both passenger trains and maintenance vehicles that are equipped with the onboard ATC subsystem. Acceleration and other functional elements of the rolling stock shall be taken into consideration in the SBD which shall include the following characteristics:

- Train operates at just below the intervention speed until it experiences an acceleration failure (at maximum acceleration) at the same time as the start of the service braking curve should begin for the obstruction ahead.

- Acceleration is cut off after a defined time following train speed exceeding the intervention speed limit; the train coasts at a constant speed for a period defined by the reaction time to apply the emergency brake. Allowances shall also be made for the build-up of full emergency braking effort.
- In the event that ATC determines that the train is not braking within the calculated parameters, an emergency brake application shall be commanded. The train shall apply braking at the emergency rate (including eddy current) and electromagnetic brakes and wheel slide protection shall be active; the ATC design shall assume that only emergency friction and wheel slide protection is applied.

Allowances shall be made for gradient, overhang (distance between outer end and the first axle), location error of the onboard ATC subsystem including sensors, speed measurement error of the onboard ATC subsystem including sensors, and all latencies and reaction delay times within the relevant ATC and RS subsystems.

Management of the safety critical interface between ATC and RS is defined in detail by the Safety and Security Management Plan (SSMP). The SBD shall be maintained throughout the design process for both ATC and RS.

The safe braking principles of train separation shall be consistent with IEEE 1698 – IEEE Guide for the Calculation of Braking Distances for Rail Transit Vehicles (2009) Figure 24-1 and for speed limits on curves with Figure 24-2.

Figure 24-1: Safe Braking for Safe Train Separation Principles

IEEE Std 1698-2009
IEEE Guide for the Calculation of Braking Distances for Rail Transit Vehicles

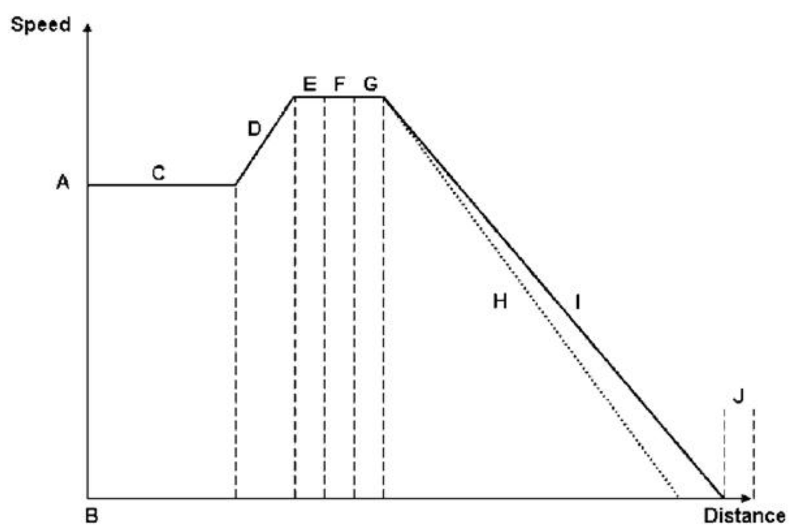

Figure 1—Braking model

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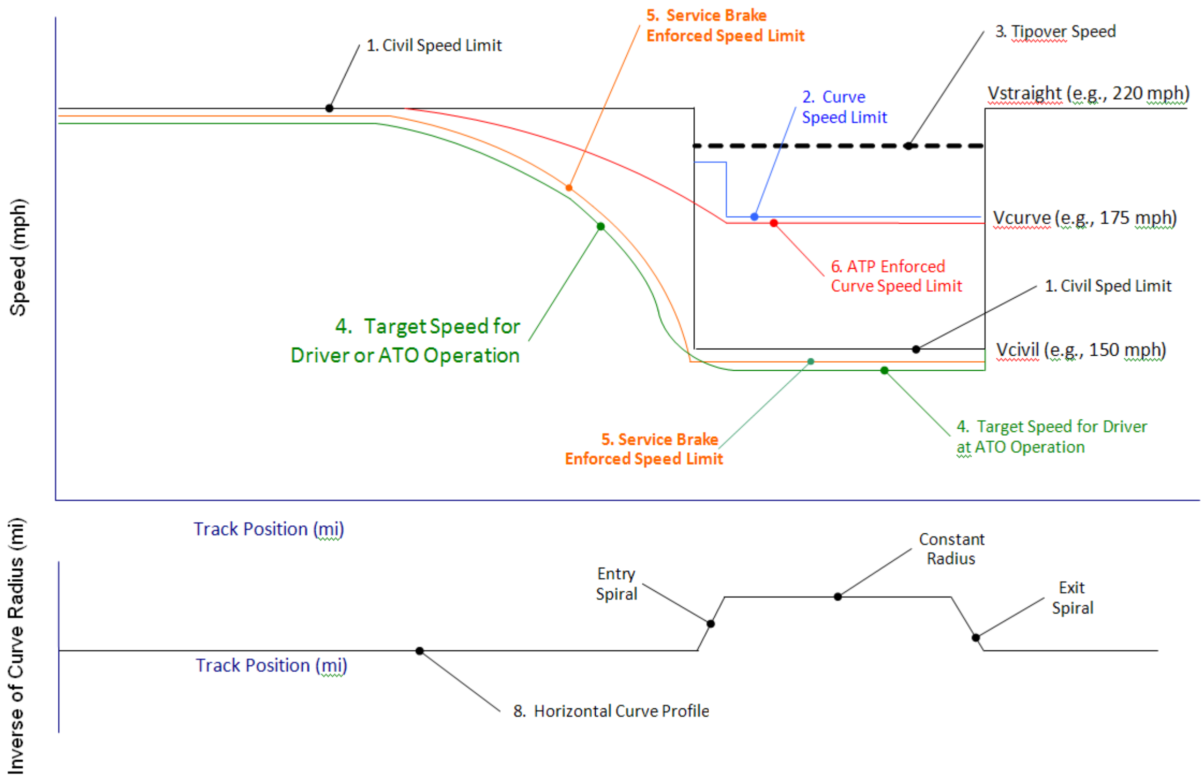
Figure 24-2: Safe Braking for Curve Speed Enforcement Principles



24.3.11 Speed Limits

Speed limits on horizontal curves will be provided to the ATC Designer in the following formats:

- Comfort Limits: speed calculated at 3 inches superelevation imbalance
- Not-to-exceed Limits: speeds calculated at 6 inches superelevation imbalance

Speed limits on other track sections will be provided as civil speed limits.

ATC shall enforce the civil speed limits and not-to-exceed limits in a vital manner for protecting against obstructions including trains ahead and unlocked switches. ATC may enforce comfort speed limits in a non-vital manner when enforcing speeds for curves and turnouts. Where curves and obstructions coincide in the limits of a train's MA, ATC shall enforce speeds in the more restrictive manner.

24.3.12 Hardware Requirements

Hardware shall be developed under a comprehensive program that ensures that safety-related maintainable hardware will be delivered. The program shall be a documented, certified SIL 4 or equivalent system for vital subsystem hardware.

The design shall fulfill the specified operational and safety requirements.

Hardware shall comply with appropriate sections from the following codes and standards:

- EN 50129 – Railway applications – Communications, signalling and processing systems – Safety related electronic systems for signaling (2003)
- EN 50159 – Railway applications – Communications, signalling and processing systems – Safety-related communication in transmission systems (2001)

ATC equipment shall be located in houses and cases that shall be designed and supplied as part of this system contract and also at the Operation Control Center (OCC) and Regional Control Center (RCC) equipment and control rooms, and offices that will be designed and built by others. Enclosures in the open shall comply with National Electrical Manufacturer's Association NEMA 4 standard.

Equipment on the wayside shall be located in houses and locations cases that shall be located along the ROW. Space provision for multiple houses has been made at all interlocking sites. Additional space for ATC equipment has been provided for in each station communications and ATC equipment room. The actual equipment houses, foundations and connections to utilities, power, and cable trough interface points shall be designed in detail and provided by the signal Designer.

Equipment onboard high-speed passenger and work trains shall be installed in purpose provided lockers on the car body, in antenna locations on or close to the train roof, externally mounted beneath the car body, and externally mounted on the sprung and unsprung components of the trucks. In addition to the EN standards cited above, onboard hardware shall also comply with the requirements of the rolling stock specification "Section 4: Climate and Environment".

Other equipment along the wayside shall be installed on or adjacent to the track and in location cases that comply with the clearance standards for fixed equipment. All foundations for houses and cases shall be designed and provided by the Designer in compliance with the interface definition with elevated, at grade, in trench, and in tunnel rights-of-way.

Cables shall be installed in the multi compartment cable trough designed and supplied by others. Provisions have been made for access of cables in and out of the cable trough on both sides to connect to track and wayside mounted equipment. Conduits shall be provided to connect between the provided entry and exit points from the cable trough to the Designer supplied equipment and cases.

Space provisions have been provided in other facilities including stations and maintenance of equipment and infrastructure yards and shops. Refer to the *Stations* chapter of this Design Criteria.

Wayside equipment including cases, housings, cables, signals, etc. shall be located with reference to clearance constraints for fixed equipment as described in the *Trackway Clearances* chapter of these Design Criteria and the associated Standard and Directive Drawings.

24.3.13 Software Requirements

Software (including firmware and databases) shall be developed under a comprehensive program that ensures that safety-critical, maintainable software will be delivered. The program shall be a documented, certified SIL 4 or equivalent system for vital subsystem software.

A robust configuration management scheme shall also be used to minimize any risks from placing incompatible and incorrect software versions in the field.

The software requirements specified herein shall apply to all Designers and Original Equipment Manufacturers (OEMs) that deliver software products for any ATC subsystem. All required software documentation shall describe the processes that will be followed by all Designers and the approach to be taken with OEMs.

Software shall be structured to the greatest extent possible such that system extensions and track configuration changes do not require complete testing and validation of the ATC system, testing shall be limited to the data portions.

Software shall comply with appropriate sections from the following codes and standards:

- EN 50128 – Railway applications. Communications, signalling and processing systems. Software for railway control and protection systems (2011)
- IEC 61508 – Functional Safety of Electrical / Electronic / Programmable Electronic Safety-related Systems
- IEEE 1558 – Standard for Software Documentation for Rail Equipment and Systems
- ANSI/IEEE 1028, IEEE Standard for Software Reviews and Audits
- IEEE 1003 – IEEE Standard for Information Technology – Portable Operating System Interface (POSIX)
- IEEE 1008 – IEEE Standard for Software Unit Testing
- IEEE 1228 – IEEE Standard for Software Safety Plans

24.3.13.1 Safety Critical (Vital) Code

Software for safety critical (vital) subsystems shall be developed in accordance with a recognized and approved standard which produces documented, certified SIL 4 software, or equivalent.

24.3.13.2 Non Safety Critical (Non-vital)

Software for non-safety critical (non-vital) subsystems shall be developed under a recognized and approved standard for reliable software which produces a minimum SIL 2 or equivalent software.

24.4 Related Documentation

Related documentation includes other chapters of these Design Criteria and the Rolling Stock Technical Specifications.

24.5 Automatic Train Control Functional Requirements

24.5.1 Onboard Functions

The ATC onboard functionality shall establish and continuously supervise and enforce each train movement along a safe path (Movement Authority) established by the wayside ATC and transmitted to the onboard ATC subsystem. The onboard ATC subsystem shall perform the following functions:

- Communicating with ATC trackside and wayside mounted equipment may include the following:
  - Transponder (Eurobalise or other)
  - Track circuit conveyed signals, with coded information transmitted in the running rails of a track circuit occupied by a specific train
  - Radio transmission from wayside and distant antennas
- Communicating information and alarms to the Locomotive Engineer via the operating display(s)
- Accurately determining the train location and correctly using the location in the generation of speed distance profiles. It shall be possible to determine the location of the entire train taking into account error of odometry and transmit it to the control center.
- Indicating actual train speed to the Locomotive Engineer on the display unit. There shall be no discrepancy between the speed shown to the driver and the speed used for supervision of MAs and speed limits functions.
- Ensuring the onboard databases are the correct ones, modifying them correctly with temporary limits transmitted from the wayside, and updating the database when permanent updates are transmitted from the wayside.
- Accurately calculating the dynamic speed-distance profile, an emergency braking curve, and a service braking curve from the train's present location to its limit of MA and other supervised locations in accordance with the SBD.

- Supervising train speed against the authorized dynamic speed profile, and enforcing a speed reduction when needed, including commanding both retrievable and irretrievable penalty brake applications if the train sustains an overspeed condition, to ensure that the train does not pass the point being protected or pass any point faster than the not-to-exceed speed limit at that location.
- It shall be possible to permit and/or inhibit service brake applications in order to avoid trains stopping at certain locations such as in tunnels, across switches, or in traction power phase breaks.
- Speed restriction enforcement shall ensure enforcement over the complete train length including allowing for position uncertainty.
- It shall be possible to define certain locations (e.g., tunnels) where speed increase is related to the front of the train.
- In protecting trains from obstructions including other trains and unlocked switches, using a brick wall approach to calculate the speed-distance profiles which protect the point beyond which a train must not pass.
- Correctly selecting and implementing the mode of operation.
- Providing the necessary intervention actions per the speed supervision function.
- Enforcing temporary speed limits and work zone commands received from the wayside.
- Providing intervention actions per wayside ATC commands, in response to the interfaced condition detectors, including seismic activity, intrusion, excessive wind speed, landslide, high water, excessive rainfall, etc. The ATC responses shall include stop now commands, restricted speed and alarm indications to Dispatchers and others. Specifics of the nature of responses shall be determined during the detail design phase.
- Supervising the accurate berthing of trains at station platforms and ensuring correct-side door operation.
- Correctly establishing the train dynamic and static characteristics.
- Providing ATO functions including interfacing with the rolling stock propulsion and brake subsystems to control train movement along the ROW in ATC-ATO mode. ATO movements shall be subject to ATP limitations and to the station stop schedule. ATO movements will be available within the yard only for movements between the main track and yard transition tracks.
- Adjusting acceleration and braking rates, and speeds in response to commands from the wayside system to meet schedule regulation requirements.
- Monitoring of ATC and train equipment health status and reporting to the ATC wayside and central; includes interfacing to onboard non-ATC subsystems to transmit subsystem health data to the wayside and central.
- Supporting degraded mode operations include the following:

- Initializing the onboard ATC functionality
- Providing degraded mode operations when selected by external input
- Isolating onboard ATC functionality when selected by external input

- Recording data for regulatory purposes.
- Recording data and transmitting it to the wayside for maintenance purposes.
- Forwarding information and commands to the Locomotive Engineer's displays and interfacing to rolling stock subsystems as needed to support other functions include the following:
  - Opening and closing passenger train ventilation flaps
  - Raising and lowering the pantograph(s)
  - Opening and closing the main power switch to respect phase break operational requirements
- Interfacing with defect sensors on the rolling stock and conveying alarms and events to the control center(s) and correctly responding with an ATC intervention where defined (emergency brake application, service brake application, etc.).
- Providing and monitoring ATP-enforced limitations on train performance to improve SBD performance, including limitation on train acceleration and speed in terminal areas.
- **Operating Modes** — A minimum of four ATC operating modes shall be provided
  - **ATC Mode** — power and brake commands are made by the Locomotive Engineer but MAs with continuous overspeed supervision are enforced by the onboard ATC subsystem.
  - **ATC-ATO Mode** — power and brake commands are transmitted to the train subsystems by the onboard ATC equipment and MAs with continuous overspeed supervision are enforced by the onboard ATC subsystem.
  - **Restricted Manual Mode** — power and brake commands are made by the Locomotive Engineer but with a continuous maximum speed limit (restricted speed) enforced by the onboard ATC subsystem.
  - **Yard Mode** — power and brake commands are made by the Locomotive Engineer but with a continuous maximum speed limit (Yard speed) enforced by the onboard ATC subsystem. For enforcement of wayside signals in the yard see the *Yard Signaling* chapter of these Design Criteria.
- A Bypass function shall also be provided that allows the Locomotive Engineer to break a seal on a cab switch. Train in Bypass will have the ATC functions cut-out and will be operated by the Locomotive Engineer subject to a maximum speed of 59 mph which will be enforced by the Rolling Stock subsystem.
- Transition between ATC and Yard modes shall be as follows:

- Trains shall enter a yard transition track from the main track in ATC or ATC-ATO mode. Trains shall be enforced to stop at the signal controlling entry to the Yard tracks at the yard end of the transition track unless the train is able to transition to Yard mode once the train is completely within Transition track limits, Yard mode is available, and the Locomotive Engineer acknowledges the mode change. Once in Yard mode, the Locomotive Engineer will control train movement in accordance with the signal aspects subject to the enforcement of yard speed limit and enforcement of red signal aspects by the onboard ATC subsystem. If the transition to yard mode does not occur in time, ATC shall ensure the train stops before passing the signal controlling entry to the Yard. Once stopped, the Locomotive Engineer may manually select yard mode.
- Trains entering a transition track from the yard shall do so in Yard mode. If a valid MA is received by the train at any point once the front of the train is on the transition track, the onboard ATC shall automatically transition to ATC mode. The exit signal at the main track end of the transition track shall be enforced if displaying a red aspect in both ATC and Yard modes. If the train does not transition to ATC mode automatically, the Locomotive Engineer is able to operate a switch in the cab once the train has been stopped and a cab indication is received that ATC mode is available. Once in ATC mode, the train can depart in either ATC mode or ATC-ATO mode once a MA has been received allowing the train to enter the main tracks and pass the transition track exit signal.

24.5.2 Wayside Automatic Train Control Functions

The ATC wayside shall provide the following functions:

- Supporting safe train operation at the design speeds and headway in both directions on all main tracks and through interlockings.
- Assembling data for MAs including track description, speed limits (permanent and temporary), and physical limit of movement allowed, and orders for individual trains and ensuring the secure and reliable transmission of each MA to the correct train.
- Route setting and locking by means of interlocking functions.
- The prevention of routes being set and cleared for high-speed trains onto non high-speed tracks.
- The prevention of routes being set for non high-speed trains (including commuter, Amtrak, and freight) to dedicated high-speed tracks.
- Implementation of PTC functions enforcing speed limits, train separation, compliance with route limits, and prevention of intrusion into work zones by the ATC wayside and onboard subsystems.
- Wayside home signals shall be provided to give clear to next interlocking aspects for ATC unequipped and failed trains. Approach fixed signs shall be provided to give notice of signal ahead to non-ATC trains.

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- Integration with track-side signaling equipment including interlockings, wayside signals, and track circuits.
- Interfacing with wayside detectors (where provided) including hot box, dragging equipment, landslides, seismic activity, intrusion, excessive wind speed, flood, excessive rain, track deformation, etc. Wayside detectors shall be located on the ROW and also on adjacent railroads on approach to where tenant train may enter the ROW.
- Transmitting the status information received from wayside signaling equipment to the onboard ATC subsystem.
- Communicating with the onboard ATC subsystem by means of one or more of the following media:
  - Fixed and variable message transponder (Eurobalise or similar)
  - Radio
  - Coded track circuit
- Wayside to train communication by means of inductive links using transposed conductors laid on the track or at the wayside is not acceptable.
- Communicating with the ATS to facilitate route setting and other supervision functions, alarm and event notification, schedule regulation, and subsystem maintenance functions.
- Communicating with customer information systems including customer information signs and public address systems providing real time train ID and schedule adherence data.
- Snow melters including heaters for power operated machines to ensure that ice and snow does not accumulate and prevent their normal operation. Such provision is required in interlocking locations where ice and snow is prevalent. Remote control of the snow melters shall be provided from the OCC and RCCs with various modes of operation including automatic (local thermostat and humidity detection active), and snow melters on and off.
- Traction power phase break requirements; Coordinate the ATC wayside and system design with the traction power and OCS designs to ensure that trains cannot normally be stopped or slowed by the ATC system in approach to or within a phase break section such that a train cannot operate through the phase break without stalling.

24.5.3 Automatic Train Supervision Functions

ATS shall provide the following centralized control and supervision functions. ATS functionality, subsystem performance, and hardware requirements shall be part of the ATC system.

- ATC shall be controlled, supervised, and monitored by ATS from the OCC or the RCCs.

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- Train routing; The ATS shall provide automatic and remote manual control of interlockings, including route setting and canceling, and individual switch operation. Automatic train routing shall provide sub-modes by the following:
  - Schedule
  - First come, first served
  - Train run ID
- Dispatching shall be achieved by the clearing of signal routes for trains about to depart, allowing sufficient time for last minute passengers to board and for the doors to close and lock. Signals or MAs shall be held against trains to prevent them from departing stations and yards early.
- Scheduling: The ATS shall store multiple versions of the operating schedule and allow real-time editing by dispatchers and operating supervisors, to cancel, add, or adjust trip information for individual and groups of trains. The ATS shall automatically regulate trains in accordance with the timetable amended or otherwise.
- Temporary Speed Restrictions (TSRs) and work zones shall be entered at ATS workstations and shall be transmitted to and implemented in the field and onboard by the respective ATC subsystems into the PTC portion of the ATC system for enforcement by the onboard ATC.
- Access to the ATS and its functional layers shall be password protected. Management of functional layers and of passwords shall be performed by a System Administrator, Chief Dispatcher, or equivalent.
- ATS facilities shall be provided in the OCC, RCCs, and training facilities to allow for playback and related analysis of events following incidents and emergencies using ATS recorded data and for training dispatchers and managers.
- ATS facilities shall be provided to enable the training of dispatchers and managers. The simulator functions shall allow the creation of scenarios both from scratch and from recorded data by a trainer. They shall allow the trainee to manage the scenario through to a conclusion. A separate set of workstations shall be provided for training purposes. The training facilities shall also be available for playback of events and incidents.
- ATS facilities shall be provided to enable construction and evaluation by simulation of new timetables including supplements to existing timetables and for minor and major editing of existing timetables.
  - ATS shall interface to passenger information facilities including customer information signs and audible public address subsystems with train status information for display at passenger stations and other public locations.

24.6 Grounding, Bonding, and Lightning Protection System

Grounding, bonding, and lightning protection requirements are defined in the *Grounding and Bonding Requirements* chapter of these Design Criteria.

The grounding and bonding design shall meet requirements for safety and function including safe touch potential limits, immunity from lightning strikes, ensuring the integrity of track circuit operation and detection of rolling stock, and safe operation in the event of equipment failures.

24.7 Onboard Equipment

All onboard hardware shall meet the requirements of EN 50125-1, Railway applications; Environmental conditions for equipment; equipment onboard rolling stock, and with the requirements of the rolling stock specification “Section 4: Climate and Environment”.

Preference shall be given in the design to equipment that is mounted on the railcar body as opposed to the truck.

Onboard equipment including housings, cables, sensors, cables, etc. shall be located with reference to the rolling stock dynamic envelope (loading gauge) constraints as described in the *Trackway Clearances* chapter of these Design Criteria and the associated Standard and Directive Drawings.

24.7.1 Display Unit

The onboard ATC display unit shall be a Human Machine Interface (HMI) that complies with all relevant parts 229 and 236 of 49 CFR. It shall provide ergonomically acceptable visibility of ATC displayed indications and ATC functions that require train operator interaction with the display. Reference shall also be made to UIC 612 – 0 - Driver Machine Interfaces for EMU/DMU, Locomotives, and Driving Coaches – Functional and system requirements associated with harmonized Driver Machine Interfaces.

24.7.2 Data Radio Display

The data radio display unit for ATC and voice radio functions shall be an HMI that effectively displays the radio functions and interactive controls. The HMI shall also comply with 49 CFR Part 236, Appendix E. Reference shall also be made to UIC 612 – 0 - Driver Machine Interfaces for EMU/DMU, Locomotives, and Driving Coaches – Functional and system requirements associated with harmonized Driver Machine Interfaces.

24.7.3 Speed and Location Determination

The on-board ATC subsystem shall determine train speed and location using sensors and subsystem logic in a combination that provides adequate safety-critical accuracy, reliability, and availability, in the environment in which the equipment is mounted on the RS. Non-truck mounted equipment shall be preferred over truck mounted equipment.

Different combinations of sensors may be used for vital than those used for non-vital applications.

24.7.4 Antennas

The design for the location of all antennas on the rolling stock including ATC data radio, ATC balise readers, and voice and other data radio, shall be such that reliable communication is assured at the extremes of the track geometry and route geography that the rolling stock traverses. Rolling stock movement and dynamic and static behavior shall be taken into account.

The location of antennas on or about the vehicle roof and underneath the RS floor shall take into account non-ATC antennas and other equipment and structural elements that might affect radio and transponder detection and communication.

24.7.5 Electronics

The on-board ATC subsystem shall meet the allocated reliability and availability requirements for onboard. It shall also meet the maintainability requirements with easy access for diagnostics and ease of replacement modules.

24.7.6 Interfaces with Rolling Stock Subsystems

Refer also to the *Rolling Stock-Core Systems Interfaces* chapter of these Design Criteria.

24.7.6.1 Propulsion

The ATC on-board equipment shall interface to the RS propulsion subsystem to provide the following functions:

- Vital propulsion cut-off during overspeed or in approach to MA limit.
- Non-vital command of tractive effort in ATC-ATO mode of operation.
- Non-vital propulsion and regenerative brake cut-off and restoration when approaching and leaving an OCS/Traction Power Supply System (TPS) phase break, based on ATC location data for phase break start and end.
- Vital limit on train acceleration and speed when approaching a bumping post.

24.7.6.2 Brakes

The ATC onboard equipment shall interface to the rolling stock braking subsystem to provide the following functions:

- Non-vital command of variable service brake effort in ATC-ATO mode.
- Non-vital command of service brake following an overspeed.
- Vital emergency brake command as a penalty (to zero speed).

24.7.6.3 Train Doors

The ATC onboard equipment shall interface to the RS door subsystem to provide the following functions:

- Command of door release on correct side for a train berthed at platform.
- Command of door inhibit for end door(s) where trains may be stopped in a station but not be fully berthed due to a short station platform.
- Detection of doors closed and locked, the loss of which will result in a penalty enforced (service) brake by ATC.

24.7.6.4 Power Switching and Air Flaps

The ATC onboard equipment shall interface to the RS subsystems to provide the following functions:

- Commanding opening of the main circuit breaker when approaching and running through an OCS/TPS section break and reclosing upon leaving the section break, based on ATC location data for the phase breaks.
- Commanding the closure of air pressure flaps or equivalent devices when approaching tunnels and commanding their opening upon leaving, based on ATC location data for tunnel portals.

24.7.6.5 Flange Lubrication System

The ATC onboard equipment shall interface to the appropriate RS subsystem to provide the following functions:

- Turning on and off onboard flange lubrication equipment when operating through curves and special trackwork, based on ATC location data for lubrication locations.

24.7.6.6 Hot Axle Bearing and Other Sensors

The ATC onboard equipment shall interface to the RS subsystems to provide the following functions:

- Sending event and alarm messages to the OCC and other locations that are generated by onboard diagnostic systems including hot axle bearing detectors

24.7.6.7 Other Interfaces

The RS shall provide for the mounting locations, cabling between the sensors and the onboard ATC package location, and other environmental considerations as specified.

24.7.7 Event Recording

The onboard ATC subsystem shall record data for diagnostic and record keeping purposes and also shall also interface to the onboard data and event recorders so as to be in compliance with the CFR regulations.

24.8 Wayside Equipment

All wayside equipment shall be designed to meet the relevant recommendations of the AREMA C&S Manual of Recommended Practice and to accommodate additional forces, shock, and vibration resulting from trains passing at up to 250 mph.

Loading design of houses, cases and other enclosures, signals, and other wayside equipment mounted on elevated structures shall comply with the limits defined in the *Structures* chapter of these design criteria.

24.8.1 Signals

All wayside signals installed along the ROW including main tracks and transition tracks shall meet the recommendations of the AREMA C&S Manual of Recommended Practice Parts 2.1.1. Use and placement of wayside ATC signals will be further described in the Specifications and Standard and Directive Drawings.

The purpose of wayside signals shall be to support degraded modes of operation in the event of failures of the ATC subsystems and components. Wayside signals will not be required to control the movement of trains under normal ATC operating modes. Wayside signals shall provide indications to the Locomotive Engineer of a train operating in degraded mode, of the status of routes through interlockings and the status of the block to the next interlocking. Signals shall display a red stop aspect where a route is not cleared or where the block is not clear to the next interlocking (for approaching non-ATC trains. Signals shall be dark when a route is clear for ATC active trains. Approaching ATC trains shall send their ATC status to the wayside to enable the interlocking to suppress the clear aspect.

Wayside signals shall be interlocked with each other and the track switches. The signal aspects shall provide visual indication to the Locomotive Engineers of non-ATC trains of the status of the route ahead to the next interlocking. When ATC trains are operating in normal ATC modes such as ATC and ATC-ATO, the signals shall be dark and indicate a "Proceed on Cab Signal" instruction.

A red aspect shall mean stop to ATC and non-ATC trains.

Dwarf style signals shall be used except where aspect visibility and sighting distances at train speeds in degraded mode operation require high signals.

24.8.2 Wayside Signs

Signs installed along the ROW as part of the ATC system shall meet the recommendations of the AREMA C&S Manual of Recommended Practices Part 14.6.1, except that retro-reflective signs shall be used rather than enamel or vitreous enamel signs.

Signs shall be similar to signals in that they shall be visible to the Locomotive Engineer to safely allow for an approach speed defined by 49 CFR 236 Subpart I and per AREMA recommended practices. Sign design shall also be consistent with the requirements of *Civil* chapter of these Design Criteria.

Signs shall be provided as a minimum at the following locations:

- At track circuit block boundaries between interlockings.
- At station approaches at the start of service braking distances at speeds defined by degraded mode operation.
- At interlocking approaches at the start of service braking distances at speeds defined by degraded mode operation.

24.8.3 Track Circuits

The ATC wayside train detection subsystem shall be comprised of track circuits which are compatible with the RS and which maximize the ability to detect broken rails. The electrical characteristics of the RS wheelsets including the impedance of the wheel/rail interface shall be consistent with the specified track circuit shunting sensitivity. The track circuits shall be compatible with the conducted and inductive emissions of the RS.

Other train detection systems such as axle counters may be used in addition to, but not instead of, track circuits if needed for specific functions or to support the system safety and performance criteria.

Axle counter equipment shall be of proven design with 5 years or more demonstrable operation in a similar high speed rail environment.

Broken rail detection shall be provided through the use of track circuits which shall also be the primary means of wayside train detection. Track circuits shall meet the requirements of 49 CFR 236. Shunt fouling is not allowed on diverging routes with speed exceeding 45 mph.

Track circuits shall conform to the AREMA C&S Manual of Recommended Practice, Section 8; Track Circuits, as applicable in electrified territory.

All main, interlocking and transition tracks shall be track circuited. The number of and the placement of the track circuits shall be determined during final design based on the following criteria:

- For headway purposes the track circuits shall be of sufficient length in order to provide the minimum design headway.
- Track circuits shall be short enough so as to reliably shunt beneath trains of any configuration including high-speed, work trains, and single work train locomotives.
- The overall number of track circuits shall be minimized to reduce procurement and life cycle costs.

Track circuits shall reliably detect revenue RS, high-speed MOI equipment, and locomotive hauled work trains. High-speed MOI equipment is defined as equipment that can operate at 60 mph or faster. The preferred shunting sensitivity of track circuits shall be 0.25 ohms. A higher shunting sensitivity value is allowed. Shunting sensitivity shall be demonstrated to detect a broken rail with cross bonds between tracks no further than 12,000 feet apart. The Designer shall design the cross bonding scheme taking into account the requirements for shunting sensitivity, broken rail detection, and step and touch potential of the rails, working in coordination with the traction power Designer. Refer to the *Grounding and Bonding Requirements* chapter of these Design Criteria.

The design shall take into account the specified rail to rail impedance Refer to the *Trackwork* chapter of these Design Criteria.

Jointless track circuits are preferred for track circuits between interlockings.

Track circuit equipment at the boundaries between adjacent track circuits outside of interlocking limits shall be installed in enclosures mounted adjacent to the main tracks in line with the OCS poles.

Track circuit occupancy and equipment health status information shall be transmitted from each track circuit receiver location to the adjacent interlockings in each direction. This information shall be transmitted as vital information. Connections to interlockings may be made over copper wire in a cable or in a dedicated ATC fiber cable. If appropriate to the ATC system, MA information shall be transmitted from the interlockings to the leading occupied track circuit by similar means. Wireless transmission shall not be used for transmission of track circuit information between the wayside track circuit equipment and the adjacent interlockings. The cable used for transmitting track circuit information to the interlockings shall be installed in the cable troughs.

24.8.4 Interlockings

Interlocking functions shall be in accordance with the 49 CFR 236 Subparts A through I, except as modified by the FRA Guideline documents.

Microprocessor based interlockings shall be used.

Vital communication between adjacent interlockings shall be provided.

Vital communication with adjacent yard signaling systems shall be provided.

24.8.5 Local Control Panels

Local Control Panels for the setting and canceling of routes together with the individual operation of signals and switches shall be provided in each signal house and also in station control rooms. These panels shall only be used in the event of failures and similar emergencies or to facilitate testing during maintenance activities. The capability to take local control at the Local Control Panel shall be protected by a log-in procedure that shall prevent unauthorized local action if the interlocking is in communication with the ATC-ATS.

24.8.6 Impedance Bonds

Air cooled impedance bonds shall meet the current capacity required for the RS operation and shall meet the grounding and bonding requirements as described in the *Grounding and Bonding Requirements* chapter of these Design Criteria.

24.8.7 Switch Machines

Power operated switch machines shall be provided on switches and moveable frogs on the main tracks of sufficient power so as to reliably operate each switch type. Where multiple switch machines are required per switch point and frog, a control device to coordinate the effort of multiple machines shall be provided. Correct switch machine operation is critically important for on-time performance, therefore, the switch machines shall be highly reliable and dependable and readily maintainable to ensure that the ATC system meets its RAMS requirements.

Switch detection shall be arranged such that each end of a crossover is detected independently. If detection is lost on one end of a crossover, train movement at restricted speed only shall be allowed across the detected end in the normal position.

AREMA standard compliant machines are preferred.

Switch machine layouts, mounting, and connection details shall be coordinated with the Trackwork Designer.

24.8.8 Equipment Enclosures

Equipment enclosures in the form of houses and cases that meet the environmental requirements of the project and provide security from access by non-authorized persons shall be provided. Cases shall provide easy and safe access for inspection and maintenance. All doors and panels shall be located and secured so they cannot be struck by passing trains or blown shut. The enclosures, doors, and panels shall be located so as to minimize risk of maintenance personnel being struck by passing trains when working on the equipment inside the enclosures.

A telephone instrument shall be provided in each house.

Houses shall be provided with fluorescent lighting.

Houses and equipment cases shall be provided with an intrusion alarm system that shall be provided with a delay timer that shall allow a maintainer to deactivate the alarm following authorized access to the house or case.

Houses shall be provided with a fire detection and alarm system.

All alarms shall be transmitted to the OCC through the communications system, refer to the *Communications* chapter.

Compounds have been provided by others at interlocking sites and within yards on which to locate ATC houses and cases. Cases on elevated structures shall be mounted in locations provided with access points to the cable trough and to the trackway itself by others.

Grounding of houses and cases shall comply with the requirements of *Grounding and Bonding Requirements* chapter of these Design Criteria.

See section 24.3 above for details of seismic and structural design of equipment enclosures.

24.8.9 Insulated Joints

Insulated joints shall be kept to a minimum on the main tracks. Jointless track circuits are preferred. Where used, insulated joints shall be of the glued type and pre-assembled before being brought to the site and welded in place. The strength and integrity of the joint and its insulation shall be compatible with the forces imparted by high-speed train operation.

Insulated joints shall be provided at entrances to interlockings, within interlockings to provide trailing release functions between crossovers and turnouts and within special trackwork as needed.

24.8.10 Cables, Cable Trough, and Conduit

Cables shall comply with AREMA standards for cables and shall be constructed of materials to suit the physical environment and installation methods with which they are installed. Exterior components of the cable shall be zero smoke, zero halogen when installed in underground and enclosed facilities. All cables shall be run in ducts, cable troughs, or conduits. No cable shall be laid exposed directly on ballast, on non-ballasted track, or buried directly underground.

Cable troughs along the main tracks and within Yards (cable trough) will be designed and supplied by others. Provisions have been made for the entry and exit of cables to and from the cable trough every 30 feet. Refer to *Civil* chapter of these Design Criteria.

Where required to link ATC equipment with the cable trough and other locations and facilities, the cable trough and ducts shall be of sufficient strength and integrity for the environment of high-speed train operation. Where power cables carrying circuits in excess of 120 volts are run

in ducts or troughs, these cables shall be physically separated from other signal and communications cables using the separation rods in the cable trough or by using separate conduits.

Cable troughs will have lids that protect against access by unauthorized persons.

Cable troughs and conduit that cross under tracks will cross perpendicular to the tracks.

Connections between cable troughs and other sleeves and ducts provided in the infrastructure including the track slabs shall be made using conduits. Connections between cable troughs, cable vaults including those provided for under-track crossings, ATC houses and cases, and other external equipment such as power transformers, shall also be made in conduit.

24.8.11 Radio Block Control Centers

If a radio based ATC system is implemented (ERTMS or similar), the MAs for trains shall be determined by the RBC, part of the wayside control equipment. The functional interfaces between RBCs shall be in accordance with ERA/UNISIG SUBSET 039 – Functional Interface Specification for the RBC/RBC Handover. The technical interfaces between RBCs shall be in accordance with the following:

- ERA/UNISIG SUBSET 097 – Requirements for RBC-RBC Safe Communications Interface
- ERA/UNISIG SUBSET 098 – RBC-RBC Safe Communication Interface
- ERA/UNISIG SUBSET 099 – Test Specification for Safe Communication Interface

In addition, the interface between the wayside part of the radio network and the RBCs shall be in accordance with ERA/UNISIG SUBSET A11T6001-12 – MORANE Radio Transmission FFFIS for Euro Radio.

24.8.12 Transponders

Where transponders are used, standard Eurobalises or other passive and/or active data transponders may be used (including the Amtrak ACSES device as used on the Northeast Corridor). The transponder design including physical size, transmission power, and data rate shall be compatible with the rolling stock mounted transponder antenna that will pass over the transponder antenna at a maximum design speed of 250 mph.

If Eurobalises are used, it shall be in accordance with ERA/UNISIG SUBSET 036 – Form Fit Function Interface Specification (FFFIS) for Eurobalise and deployed in accordance with ERA/UNISIG SUBSET 040 – Dimensioning and Engineering Rules and other relevant documents.

24.8.13 Signal Power

Power for signal equipment shall be provided from at least two sources with back-up batteries at each location. The preferred primary power source is a feed from the OCS via step-down

transformer to provide 480V single phase supply to the ATC enclosure. Additional transformers, rectifiers, and filtering equipment shall be provided to distribute the necessary regulated voltage supplies to various items of equipment housed in the enclosure or fed from it.

A circuit breaker disconnect shall be provided on the low-voltage side of the transformer, marking the demarcation between OCS and ATC maintenance responsibility. Alternative power sources may consist of one or more of the following — feed from local utility, feed from an adjacent facility which has a direct utility feed, solar panels, and wind turbines.

Battery backup shall be provided in all locations with a guaranteed minimum duration of 8 hours when maintained per the manufacturer's recommendations.

In addition, each ATC facility shall be provided with a plug-in point to receive power from a portable generator.

Loss of primary signal power shall not result in the loss of any ATC function for duration of the charged life of the batteries. The status of power supplies and batteries shall be alarmed and indicated remotely through the ATS.

24.8.14 Event Recording

The central, wayside, and onboard ATC subsystems shall record data for diagnostic and record keeping purposes. The onboard event recorder shall also interface to the RS onboard data and event recorders so as to be in compliance with the CFR regulations.

24.8.15 Wayside Interfaces

The wayside ATC subsystem shall interface to the following:

- Event and incident detectors (number and type to be determined) to provide indications and ATC system responses as necessary to detections.
- OCS for power supplies at certain locations.
- Utility power supplies at locations where provided.
- Grounding points provided by others.

24.8.16 Highway Grade Crossings

No highway grade crossings shall be permitted on main tracks; therefore, no warning systems or interfaces to the ATC system are required.

24.9 System Time

All pieces of ATC equipment shall derive their time reference from a single GPS Network Time System (GNTS). Each time-tagged data element within any ATC equipment item shall be

accurately time-stamped for real time control and system safety needs and also for later event and incident analysis.

24.10 Maintenance and Diagnostic Functions

All ATC equipment shall be designed with built in diagnostics and health monitoring functionality. Equipment shall be monitored such that degrading performance can be identified to the greatest degree possible and indicated as a warning through the ATS component of the Supervisory Control and Data Acquisition (SCADA) subsystem and locally in the equipment houses and cases. Warnings shall be given prior to the loss of function of the equipment. Refer to the *Supervisory Control and Data Acquisition Subsystems* chapter of these Design Criteria.

ATC equipment status shall be indicated as healthy or failed through the ATS subsystem and locally in the equipment houses and cases.

Indications shall be given in the form of color coded indications and/or in the form of text readouts in English. Alphanumeric codes shall be avoided as far as is practicable, health status messages shall be in plain text.

Design of all equipment shall consider ease of maintenance including easy access to all replaceable components and equipment that requires inspection and routine testing in place.

Maintenance and diagnostic functions and equipment shall support the ATC system maintainability requirements.

24.11 Automatic Train Supervision Subsystem

24.11.1 Automatic Train Supervision Functions

The ATS system shall provide the remote supervision and remote control facilities for the ATC system. Many of the functions including route setting, junction management, and schedule regulation shall have automated functional options with the ability for dispatchers and managers to intervene as necessary.

The ATS shall also provide event recording facilities of all data input to the system and commands sent from the system.

All ATS equipment needed for standalone operation shall be installed in the OCC and in at least two additional RCCs. Under normal conditions, the OCC shall have overriding command and control. Staff at the RCCs may supervise and dispatch trains on their respective corridors and the OCC staff can supervise and dispatch trains in all other sections of the system.

Any and all control, supervision, and monitoring functions shall be possible from any workstation within the OCC or RCCs, once authorized with password protected configuration

setting functions. Servers and other processors shall be distributed such that the loss of any and all equipment at one of the control centers shall not prevent either of the remaining control centers from supervising and controlling any part of the system.

Remote workstations giving access to indications and limited command sets shall be installed in station control rooms, equipment and MOI maintenance facilities.

ATC shall provide an automatic field-fallback mode for all interlockings when unsupervised by ATS, except for terminals and major through stations, including Los Angeles. In the event of loss of ATS control from the OCC or RCCs, routes at interlockings shall automatically revert to previously programmed through routes and fleet settings, or as otherwise commanded from a Local Control Panel.

A Local Control Panel or panels shall also be provided in station control rooms to allow operating personnel to set and cancel routes in the event of a failure of ATS communications between the field sites and the OCC and RCCs, or in other special cases with approval from the Dispatcher.

A Local Control Panel shall also be provided in the interlocking control house for emergencies and for maintenance testing needs.

Regional control of each workstation shall be definable by the System Administrator. Definition of access to each set of functional levels shall be password protected. System access shall be structured such that different levels of access can be afforded to individuals based on their responsibilities and access authorization managed by the System Administrator.

24.11.2 Automatic Train Supervision Hardware (Office) Requirements

ATS hardware shall consist to the maximum extent practical of Commercial Off-the-Shelf (COTS) devices and components. Hardware shall be chosen based on its suitability to the environment in which it will operate and also to facilitate future upgrades of hardware as the COTS equipment becomes obsolete.

Loading design of ATS hardware and other ATS equipment shall comply with the limits defined in the *Structures* chapter of these design criteria.

The ATS subsystem architecture shall provide for high availability and reliability of the ATS in order to ensure that the ATC system meets the RAMS requirements.

24.11.3 Automatic Train Supervision Interfaces with Other Systems

The ATS system shall interface with other systems including:

- Traction Power SCADA to enable blocking of track sections to approaching electric trains in the event that power is off in specific sections.

- Facilities SCADA including fans and pumps to provide remote indications on the dispatcher ATS workstations.
- Tunnel facilities SCADA to provide remote indications on the dispatcher ATS workstations.
- Event and incident detectors to provide remote indications on the dispatcher workstations.
- Yard ATC for the transition of trains between the yards and main tracks and vice versa.
- Customer Information and Public Address Systems.

The ATS subsystem may be implemented as part of an integrated control system and the functions may be implemented on a common hardware platform to SCADA, security, and other control and command systems.

24.11.4 Automatic Train Supervision Power

Power for the control center ATS subsystems will be provided by others, it will be provided from redundant sources and backed up by a combination of batteries (4 hours) and diesel generators (continuous).

Chapter 25

Yard Signaling

HSR 13-06 - EXECUTION VERSION

Revision	Date	Description
0	02 Mar 12	Initial Release, R0

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Acronyms

AREMA C&S	American Railway Engineering and Maintenance-of-Way Association Communications and Signals
ATC	Automatic Train Control
ATS	Automatic Train Supervision
CHSTP	California High-Speed Train Project
IIMP	Integrated Information Management Platform
LED	Light-Emitting Diode
MOI	Maintenance of Infrastructure
MTTR	Mean Time to Restore
MTTT	Mean Time To Travel
RAM	Reliability, Availability, and Maintainability
RAMS	Reliability, Availability, Maintainability, and Safety
RSM	Rolling Stock Maintenance
SIL	Safety Integrity Level

25 Yard Signaling

25.1 Scope

The Yard Signaling system and its subsystems shall meet the requirements of the standard specifications and preliminary engineering drawings and all applicable regulatory requirements.

The term "Yard" with respect to signaling refers to the following:

- Rolling Stock Maintenance (RSM) – Facilities including the Heavy Maintenance Facility (HMF) and all Terminal Storage and Maintenance Facilities. The Yard Signal System consisting of the signals, switch machines, train detection, and the controlling subsystems shall meet the requirements of the standard, functional, and performance specifications and preliminary engineering drawings for the Yard Signal System and all applicable interoperability and regulatory requirements extracted from the System Requirements.
- Maintenance of Infrastructure (MOI) facilities – MOI Yard Tracks shall not be equipped with a signal system. However, the Transition Tracks connecting the Yard Tracks with the Main Tracks shall be equipped with Main Track Automatic Train Control (ATC) (refer to the *Automatic Train Control* chapter of these Design Criteria) and with Yard Signals protecting train movements in both directions between the Transition Tracks and the Yard Tracks.

25.2 Regulations, Codes, Standards, and Guidelines

Refer to the *General* chapter for requirements pertaining to regulations, codes, and standards.

- American Railway Engineering and Maintenance of Way Association Communications and Signals (AREMA C&S) Manual of Recommended Practices
  - Part 17 – Recommended
- European Committee for Electrotechnical Standardization (CENELEC) Standards
  - EN 50121-4 - Railway applications – Electromagnetic compatibility Part 4: Emission and immunity of the signaling and telecommunications apparatus (2006)
  - EN 50125-1 - Railway applications - Environmental conditions for equipment- Part 1: Equipment on board rolling stock (1999)
  - EN 50125-3 - Railway applications - Environmental conditions for equipment - Part 3: Equipment for signalling and telecommunications (2003)
  - EN 50126-1 – Railway applications – The specification and demonstration of Reliability, Availability, Maintainability and Safety – Part 1: Basic requirements and generic process (1999)

- CLC/TR 50126-2 - Railway applications – The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS) – Part 2: Guide to the application of EN 50126-1 for safety (2007)
- EN 50128 - Railway applications –Communications, signalling and processing systems - Software for railway control and protection systems (2011)
- EN 50129 - Railway applications –Communications, signalling and processing systems - Safety related electronic systems for signalling (2003)
- EN 50159 - Railway applications –Communications, signalling and processing systems - Safety-related communication in transmission systems (2011)

- International Electrotechnical Commission (IEC) Standards
  - IEC 60812: Analysis techniques for system reliability – Procedures for failure mode and effect analysis (FMEA)
- Institute of Electrical and Electronics Engineers (IEEE) Standards
  - IEEE 828 – IEEE standard for Software Configuration Management Plans.
  - IEEE Standard 1558, Standard for Software Documentation for Rail Equipment and Systems.
  - ANSI/IEEE STD 1028, IEEE Standard for Software Reviews", The Institute of Electrical and Electronics Engineers.
  - IEEE Standard 1003, IEEE Standard for Information Technology - Portable Operating System Interface (POSIX).
  - IEEE Standard 1008, IEEE Standard for Software Unit Testing.
  - IEEE Standard 1228, IEEE Standard for Software Safety Plans.

25.3 General Design Requirements

The Yard Signal System shall be safe and reliable, as defined by the RAMS requirements of this chapter and designed to a Safety Integrity Level (SIL)-2 level of safety.

The Yard Signal System shall incorporate the following:

- Route setting and locking by means of route logic control functions. Routes shall be protected with approach locking and overswitch (detector) locking. Sectional release shall be provided on specified tracks that will allow short turns when drilling trains between tracks. Signals shall be provided to indicate that trains may safely proceed through switch areas. Signals shall be provided to govern movements into and out of layup tracks, at approaches to shop entrances, and at entry and exit between Transition Tracks and the yard.
- Signal aspects shall be determined by switch position, route locking, and track occupancy status. Aspects shall also indicate if there is at least 656 feet of train berth space available in a

layup track. Signals shall be provided to protect all powered switches, in the mid-point of ladder tracks if a short drill move is permitted, and at the mid-point of layup tracks where up to 1,312 feet of train layup space is provided.

- Onboard ATC equipment shall enforce compliance with wayside signal aspects (stop). A single yard maximum speed limit shall also be enforced by the onboard system; lower speeds where applicable shall be signposted at the wayside and will be manually observed and complied with by the Locomotive Engineer.
- Yard tracks shall be equipped with a signal system that includes a combination of track circuits and/or axle counters, low level wayside signals, power switch machines, power operated derails, and route logic controllers that shall control train movements within Yard Limits.
- Blue flag protection for workers in the yards shall be achieved through the use of power operated switches on inspection tracks being lined and locked away from the tracks on which inspection is taking place and by a block being placed on the Yard Signal control system. Power-operated derails shall also be provided where necessary and where a particular track cannot be protected by lining switches away from that track. These derails shall also be controllable from the Yard Signal control system.
- Train location shall be detected by means of track circuits. Other train detection systems such as axle counters may be used in addition to, or instead of, track circuits. Where track circuits are used in the yards, they shall be of single rail configuration except in Transition Tracks where double rail track circuits shall be employed.
- Wayside signals shall be connected to and controlled by route logic control equipment so as to provide visual indication of the status of routes through switches and occupation of layup tracks to the Locomotive Engineers. Fixed wayside signs shall also be provided for indications to Locomotive Engineers of key locations within lay-up tracks (e.g., “Limit of 8 Car Unit Stop”, etc.).
- Yard Tracks shall be separated from main tracks by means of Transition Tracks. Train movement between the Transition Tracks and main tracks shall be under the control of the ATC system. Train movement between the Yard Tracks and the Transition Tracks shall be under the control of the yard signal system.
- Transition between Yard and ATC modes on the Transition Tracks shall be automatic, transition between ATC and Yard Modes shall be semi automatic; when ATC is able to transition to Yard Mode, an indication shall be given to the Locomotive Engineer that Yard Mode is available. Acknowledgement by the Locomotive Engineer shall cause the transition to Yard Mode to occur. If the Locomotive Engineer does not acknowledge the pending change of more, the train shall remain in ATC mode and a stop before entrance to the Yard Tracks shall be enforced. For more details refer to the *Automatic Train Control* chapter of these Design Criteria.

- Power switch machines within the yard shall be of the yard (trailable) type. Switch machines on any part of the Transition Tracks shall be of the Main Track type.
- Control and supervision of the Yard wayside Signal System shall be through a local dedicated Yard Signal control facility with a combination of control panel(s) and/or workstation(s).
- A train information management system shall be provided that allows for the designation of trainsets by maintenance personnel to specific train numbers; the train information management system shall track designated trains with their allocated information around the yard and shall exchange this information with the Yard Signal control system and the ATC-ATS subsystem.
- All enclosures and the equipment mounted within them, equipment mounted in rooms provided by others, and equipment mounted along the Right-of-Way shall be designed in accordance with the seismic considerations as defined in the *Seismic* chapter of these Design Criteria.
- The secure mounting of enclosures and equipment along the Right-of-Way shall also be accomplished in accordance with the *Structures* chapter of these Design Criteria.

25.4 Design Life

The Yard Signal System shall have the same useful life as the ATC system and is defined in the *General* chapter of these Design Criteria.

25.5 Environmental

The climatic and physical environmental specifications and performance of the Yard Signal System equipment installed at the wayside shall comply with AREMA C&S and the relevant portions of EN 50125-3, "Railway applications - Environmental conditions for equipment - Part 3: Equipment for signalling and telecommunications". In the event that these requirements are in conflict, the more arduous and restrictive conditions shall apply.

The climatic and physical environmental specifications and performance of ATC equipment installed onboard passenger trains shall comply with the criteria defined in the Rolling Stock specification "Section 4: Climate and Environment".

ATC equipment installed on work trains shall comply with EN 50125-1, "Railway applications - Environmental conditions for equipment- Part 1: Equipment onboard rolling stock".

For other climatic requirements refer to the *General* chapter of these Design Criteria.

25.6 Onboard Equipment

Onboard equipment shall enforce stop signals and yard speed limits. A single onboard ATC equipment set is preferred for main track ATC functions and yard signal enforcement. In Yards, the onboard ATC subsystem shall be in Yard Operating Mode. The details of this mode are described further in the *Automatic Train Control* chapter of these Design Criteria.

All onboard ATC hardware shall meet the environmental criteria identified in the specifications for the respective location (body, sprung part of trucks, and unsprung part of trucks). Preference shall be given in the design to equipment that is mounted on the railcar body as opposed to the truck.

In yards, the onboard ATC subsystem shall be in Yard Mode; power and brake commands are made by the Locomotive Engineer but with a continuous maximum speed limit (yard speed) enforced by the onboard ATC subsystem. In Yard Mode, red signal aspects shall be enforced with a stop command to the train braking subsystem. Enforcement shall ensure trains stop before running past an unlocked switch point or beyond the fouling point.

Onboard equipment including housings, cables, sensors, cables, etc. shall be located with reference to the rolling stock dynamic envelope (loading gauge) constraints as described in the *Trackway Clearances* chapter of these Design Criteria and the associated Standard and Directive Drawings.

25.7 Wayside Equipment

25.7.1 General

All enclosures and the equipment mounted within, equipment mounted in rooms provided by others, and equipment mounted along the Right-of-Way shall be designed in accordance with the seismic considerations as defined in the *Seismic* chapter of these Design Criteria.

The secure mounting of enclosures and equipment along the Right-of-Way shall also be accomplished in accordance with the *Structures* chapter of these Design Criteria.

Enclosure (house and case) foundations shall be designed in accordance with the *Civil* chapter of these design criteria.

Loading design of houses, cases and other enclosures, signals and other equipment mounted on elevated structures shall comply with the limits defined in the *Structural* chapter of these design criteria.

All wayside equipment except for houses shall be secured with a standard set of padlocks.

Houses shall be secured in compliance with the Access Control requirements as described in the *Civil* chapter of these Design Criteria. Preparation of sites is also described in this section. Final

site preparation shall be designed to be compatible with the requirements for placing foundations for enclosures including houses and cases and for using the compound as a working site.

All wayside equipment within a yard shall be designed to meet the relevant recommendations of the AREMA C&S and accommodate additional forces, shock, and vibration resulting from trains passing at up to 250 miles per hour (mph) on adjacent high-speed Main Tracks where applicable.

Wayside equipment including cases, housings, cables, signals, etc. shall be located with reference to clearance constraints for fixed equipment as described in the *Trackway Clearances* chapter of these Design Criteria and the associated Standard and Directive Drawings.

Spare capacity; provision for spare capacity (scalability) shall be designed into all enclosure spaces, cable conductors (copper and fiber), and network and data communication channels.

Enclosures in the open shall comply with the National Electrical manufacturer's Association NEMA 4 standard.

Wayside equipment including houses, cases, cables, signals, transponders, etc. shall be located with reference to clearance constraints for fixed equipment as described in the *Trackway Clearances* chapter of these design criteria and associated Standard and Directive Drawings.

25.7.2 Signals

All signals installed in the yards shall meet the recommendations of the AREMA C&S Parts 2.1.1 and 7.1.5. Use and placement of wayside Yard Signals will be further described in the Standard Specifications and Standard and Directive Drawings. Light Emitting Diodes (LED) shall be used for display of signal aspects.

Wayside signals shall be provided so as to be visible to Locomotive Engineers when operating within the yard limits. These signals shall be the primary means of indicating routes set and locked. Stop aspects shall be enforced.

Wayside signals shall be interlocked with each other and with the switches as part of the yard route logic controller functionality.

Signal aspects shall indicate either "stop", or that a route is clear to the far side of the switch combination, or that there is sufficient lay-up distance for a single passenger train unit clear beyond the signal.

25.7.3 Wayside Signs

Signs installed adjacent to Yard Tracks for train control or lay-up purposes shall meet the recommendations of the AREMA C&S Part 14.6.1, except that retro reflective signs shall be used rather than enamel or vitreous enamel signs.

Sign design shall also be consistent with the requirements of the *Civil* chapter of these Design Criteria.

25.7.4 Train Detection

Train detection within the yards shall be by means of single rail track circuits. Other train detection systems such as axle counters may be used in addition to, or instead of, track circuits.

25.7.5 Route Logic Controllers

The Yard Signal System shall provide route logic control functions using proven and reliable microprocessor based equipment. Safety critical requirements of the Yard Signal System are contained in Section 25.15.

25.7.6 Workstations and Control Panels

Remote control of Yard Signal System elements shall be achieved by means of a combination of workstations and control panels for the setting and canceling of yard routes, together with the individual operation of signals and switches shall be provided in each Yard Signal control tower or control room. These workstations and control panels shall be integrated into the overall system Integrated Information Management Platform (IIMP).

Stand-alone (non-IIMP integrated) control panels shall also be provided in each signal house within the yard. The panels inside houses shall be used in the event of failures and similar emergencies and also to facilitate testing during maintenance activities.

25.7.7 Impedance and Other Bonds

Impedance Bonds, where required, shall meet the current capacity required for the operation of the rolling stock and meet the grounding and bonding requirements of the California High-Speed Train Project (CHSTP); refer to the *Grounding and Bonding Requirements chapter* of these Design Criteria.

The grounding and bonding design shall meet requirements for safety and function including safe touch potential limits, immunity from lightning strikes, ensuring the integrity of track circuit operation and detection of rolling stock, and safe operation in the event of equipment failures.

25.7.8 Switch Machines

Power operated, high voltage yard style switch machines shall be provided on yard switches. The yard switch machines shall be of the trailable type. Switch machines on Transition Tracks shall be of a main line type.

Switch machine layouts, mounting, and connection details shall be coordinated with the Trackwork Designer.

25.7.9 Equipment Enclosures

Equipment enclosures in the form of houses and cases that meet the environmental requirements of the CHSTP and provide security from access by non-authorized persons shall be provided. Cases shall provide easy access for inspection and maintenance; all opening doors and panels shall be located and secured in such a manner that they cannot be struck by passing trains. The enclosures, doors, and panels shall also be located so as to minimize risk of maintenance personnel being struck by passing trains when working on the equipment inside the enclosure.

All enclosures and the equipment mounted within them, equipment mounted in rooms provided by others, and equipment mounted along the Right-of-Way shall be designed in accordance with the seismic considerations as defined in the *Seismic* chapter of these Design Criteria.

The secure mounting of enclosures and equipment within the yards, including signals, signs, etc., shall also be accomplished in accordance with the *Structures* chapter of these Design Criteria.

25.7.10 Insulated Joints

Insulated Joints shall be of the glued type and pre-assembled before being brought to the site in accordance with the *Trackwork* chapter of these design Criteria. The strength and integrity of the joint and its insulation shall be compatible with the forces imparted by train operation within the yards and maintenance facilities.

25.7.11 Cables, Cable Trough, and Conduit

Cables shall be constructed of materials to suit the physical environment and installation methods with which they are installed. Cables shall be run in ducts, cable troughs, or conduits. No cable shall be laid directly onto Ballasted or on Non-Ballasted tracks, nor shall it be directly ploughed into the ground.

Where conduits and cable troughs cross tracks, they shall do so perpendicular to the rails.

Cable troughs will be provided throughout the yards as part of the system-wide cable trough by others. Cable troughs and ducts required to connect between Yard Signal System equipment and the system-wide cable trough shall be of sufficient strength and integrity for the yard environment. Where power cables with higher voltages than 125 volts are run in ducts or troughs, these cables shall be physically separated from other signal and communications cables using the separation rods in the trough or by using separate conduits.

Cable troughs shall have lids that prevent access by unauthorized persons.

Cable troughs shall be compatible with the requirements of the *Civil* chapter of these Design Criteria.

25.7.12 Transponders

Where transponders are used in yards, standard Eurobalises or other form of passive and/or active data transponder shall be used. The transponder design shall be compatible with transponders used on main tracks provided as part of the ATC system such that a separate antenna and reader system is not required as part of the on board equipment.

25.7.13 Power Operated Derails

Power operated derails, including switch point and block, shall be provided as needed to protect tracks where work on rolling stock can take place and where switches cannot be set to divert approaching trains away from that track. Where derails are provided, they shall be power operated, connected to, interlocked with signals, and controlled by the Yard Signal control system. Derail provisions shall be consistent with the *Trackwork* chapter of these Design Criteria.

25.7.14 Yard Signal System Power

Power for Yard signal system equipment shall be provided from at least two sources with back-up batteries at each location. The preferred primary power source is a feed from the OCS via step-down transformer to provide 480V single phase supply to each Yard signal system enclosure. Additional transformers, rectifiers, and filtering equipment shall be provided to distribute the necessary regulated voltage supplies to various items of equipment housed in the enclosure or fed from it.

A circuit breaker disconnect shall be provided on the low-voltage side of the transformer, marking the demarcation between OCS and Yard signal system maintenance responsibility. Alternative power sources may consist of one or more of the following: feed from local utility, feed from an adjacent facility that has a direct utility feed, solar panels, and wind turbines.

Battery backup shall be provided in all locations with a guaranteed minimum duration of 8 hours when maintained per the manufacturer's recommendations.

In addition, each ATC facility shall be provided with a plug-in point to receive power from a portable generator.

Loss of primary signal power shall not result in the loss of any Yard signal system function for the duration of the charged life of the batteries. The status of power supplies and batteries shall be alarmed and indicated remotely through the ATS to the Operation Control Center/Regional Control Centers.

Loss of signal power and the status of batteries shall also be alarmed and indicated to the local Yard Control System.

25.8 System Configuration

The wayside yard signaling subsystem shall interface with the following:

- Main track (ATC) signaling at the Transition Tracks
- The yard remote control and supervision subsystem
- The yard Rolling Stock maintenance management subsystem
- The traction power subsystem (through the impedance bonds)

25.9 Functional Requirements

The yard signaling system shall provide the following functions:

- Setting of routes shall be done from a local control facility within each yard through workstations and a computer based control system that shall be separate from, but interfaced to, the ATC-ATS subsystem.
- Wayside signals and switches shall be interlocked; signals shall display a clear aspect when the route is set and locked and no track occupancy is detected between the signal and the opposing signal. Signals controlling routes into layup tracks shall also require a clear berth track in order to display a clear aspect.
- Where multiple routes are possible from a single wayside signal, an indicator shall be provided displaying the route destination track to the Locomotive Engineer.
- Where trains are routed to lay-up tracks where the track is partially occupied, the midpoint of the track shall be marked with a signal or fixed sign and the entry signal to the track shall show a clear aspect as long as at least 656 feet of track is unoccupied at the entry end of the track.
- Signal stop aspects shall be detected and red signals enforced by an onboard function.
- Signals at switches shall be located such that a train attempting to pass a red signal shall be brought to a stop before the unsafe location including unlocked switch points or the fouling point of a switch not set and locked for the merging move.
- Midpoint signals and bumping posts at the end of tracks shall not be absolutely enforced; the Yard Signal System shall enforce a reduction of speed (5 mph) prior to the red signal and bumping post. A worst case maximum collision speed of 3 mph with the bumping posts shall be designed for within the yard signal safe braking concept.
- Signals at shop entrances shall be located such that a train attempting to pass a red signal shall be brought to a stop before it passes the door threshold.

25.10 Yard Signal Control System

The Yard Signal control system shall provide the remote supervision and remote control facilities for yard operations. Operation of switches and signals shall be commanded by inputs to the route logic controllers by means of a computer workstation located in a dedicated room or tower within each yard. The control system shall also provide event recording facilities of all data input to the system and commands sent from the system.

A set of train management functions shall be provided that allows for the designation of specific data including unit, train, and crew IDs to be attributed to a detected train within the yard and allows for the tracking of that train and its allotted data around the Yard Tracks. The Yard Signal control system shall also exchange this data with the ATC-ATS subsystem when trains enter the Transition Tracks in preparation for entry onto the main tracks. Trains that have no data attributed to them will be assumed to be drilling in the Transition Track and no data exchange shall take place with the ATC-ATS.

25.11 Yard Signal Control System Hardware Requirements

Yard Signal control system hardware shall consist to the maximum extent practical of Commercial Off-the-Shelf (COTS) devices and components. Hardware shall be chosen based on its suitability to the environment in which it will operate and also to facilitate future upgrades of hardware as the COTS equipment becomes obsolete.

25.12 Electromagnetic Compatibility

Yard Signal System equipment shall not interfere with or be interfered with by other equipment or equipment external to the CHSTP. The Yard Signal System design shall comply with the requirements of the *Electromagnetic Compatibility and Interference* chapter of these Design Criteria.

25.13 Reliability, Availability, and Maintainability Requirements

The reliability of the yard signal system and its subsystems shall be consistent with the overall RAM requirements. RAM and safety requirements shall be defined, achieved, and maintained in accordance with EN 50126-1. Other standards will be considered on the condition that the Contractor provides a comprehensive equivalency report that maps the correlation between EN 50126-1 and their proposed standard(s).

Yard Signal System availability shall also be consistent with the availability requirements of the overall project high level thresholds. Each Yard Signal System shall have an availability higher than 99.99 percent.

Reliability targets shall be apportioned to the equipment such that the availability targets can be achieved.

Human factors contributions to RAM shall be considered as follows:

- Mean Time To Travel (MTTT) shall be a fixed defined in the contract documents reflecting the locations of MOI and RSM facilities and highway access to Yard signal system wayside locations.
- The supplier shall demonstrate that a Mean Time to Restore (MTTR) of 30 minutes is achievable. MTTR is a mean value for all yard signal system line replaceable units; it includes diagnosis of faults measured from the actual start of work on site, replacing of faulty components, testing, and placing the system back into service in the affected area. MTTR does not include MTTT.

Care shall be given throughout the design for the maintainability of all equipment including access for inspection and the replacement of all line replaceable units and to provide user friendly diagnostics. Diagnostics shall primarily be through indicators using a combination of colored LEDs and alphanumeric displays on the front face of equipment that can be readily seen by maintainers and understood without the need for reference manuals to decode the displays. Diagnostics shall also be provided that allow the use of plug in portable computers and notebooks to access internal diagnostic routines that shall facilitate the easy and rapid diagnosis of failures of the equipment. All diagnostic routines shall be protected by secure access functions.

25.14 Software Requirements

Software (including firmware and databases) shall be developed under a comprehensive program that ensures that reliable and maintainable software will be delivered. The program shall be a documented, certified software SIL-2 per EN 50128 or equivalent system for safety related subsystem software.

A robust configuration management scheme shall also be used to minimize any risks from placing incompatible and incorrect software versions in the field.

The software requirements specified herein shall apply to all Designers and Original Equipment Manufacturers (OEMs) that deliver software products for any yard signal system and subsystem. All required software documentation shall describe the processes that will be followed by the Designer, their subcontractors, and the approach to be taken with OEMs.

Software shall be structured to the greatest extent possible such that system extensions and track configuration changes do not require complete testing and validation of the Yard signaling system, testing shall be limited to the data portions.

Software shall comply with appropriate sections from the following codes and standards:

- EN 50128; “Railway applications – Communications, signalling and processing systems - Software for railway control and protection systems (2011)”
- IEEE Standard 1558, “Standard for Software Documentation for Rail Equipment and Systems”.
- Software Engineering Institute (SEI), “Standard CMMI Appraisal Method for Process Improvement (SCAMPI^{SM} Version 1.1)”.
- ANSI/IEEE STD 1028, “IEEE Standard for Software Reviews”.
- IEEE 828 – IEEE standard for Software Configuration Management Plans.
- IEEE Standard 1003, “IEEE Standard for Information Technology - Portable Operating System Interface (POSIX)”.
- IEEE Standard 1008, “IEEE Standard for Software Unit Testing”.
- IEEE Standard 1228, “IEEE Standard for Software Safety Plans”.

25.15 Yard Safety Critical System Requirements

Transition tracks shall be designed to a safety level compliant with SIL-4 as per the main line ATC system.

The Yard Signal System shall be designed to a safety level of at least SIL-2 and as follows:

- Safety shall be specified and assured in accordance with EN 50126-1 and EN 50129.
- Other standards will be considered on the condition that the Designer provides a comprehensive equivalency report that maps between EN 50126-1 and EN 50129, and other specified standards and their proposed standard(s).
- The related application guide CLC/TR 50126-2 Railway applications – The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS) – Part 2: Guide to the application of EN 50126-1 for safety (2007) shall also apply.

The design, construction, installation, acceptance, operation, maintenance, and modification/extension of the ATC system, including the development of hazard mitigation procedures and other means, shall provide a quantitative level of safety such that any single, independent hardware, software, or communication failure, or any combination of such failures, with the potential of causing death or severe injury to passengers or staff, shall not occur with a frequency greater than once per 10^4 system operating hours. This shall be documented and certified to SIL-2 in accordance with the following:

- EN 50126-1 - Railway applications – The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS) — Part 1: Basic requirements and generic process (1999).

- EN 50128 - Railway applications – Communications, signalling and processing systems. Software for railway control and protection systems (2011).
- EN 50129 - Railway applications – Communication, signalling and processing systems. Safety related electronic systems for signaling (2003).
- EN 50159 - Railway applications –Communications, signalling and processing systems - Safety-related communication in transmission systems (2011).

Tolerable hazard rates attributed to operations and maintenance actions shall be considered to be zero for the purpose of the Yard Signal System calculations.

25.16 Maintenance and Diagnostic Functions

All Yard Signal System equipment shall be designed with built in diagnostics and health monitoring functionality. Equipment shall be monitored such that degrading performance can be identified to the greatest degree possible and indicated as a warning through the Yard Signal control system. Warnings shall be given to the maximum extent possible prior to the loss of function of the equipment.

Yard Signal equipment status shall be indicated as either healthy or failed both remotely through the yard signal control system and locally in the equipment houses and cases.

Indications shall be given in the form of color coded indications and/or in the form of text readouts in English. Alphanumeric codes shall be avoided as far as is practicable; health status indications and messages shall be in plain text.

Design of all equipment shall consider ease of maintenance including easy access to all replaceable components and equipment that requires inspection and routine testing in place.

Maintenance and diagnostic functions and equipment shall support the yard signal system maintainability requirements.

25.17 Yard Signal Control System Interfaces with Other Systems

The Yard Signal control system shall interface with other systems including:

- IIMP to provide a common Human Machine Interface for Yard signaling and other control systems in the Yard control room.
- SCADA to facilitate the blocking of track sections to approaching trains in the event that power is off in Yard Tracks and to provide overview indications of the status of traction power sections within the yard

- Building and other yard facilities to prevent trains from colliding with shop entry doors and other barriers and to provide remote indications on the dispatcher workstations including shop entry door status
- Event and incident detectors to provide remote indications of Yard Signal system status on the yard controller workstations and/or panels
- The ATC-Automatic Train Supervision (ATC-ATS) subsystem for the transition of trains and associated information between the yards and main tracks and vice versa
- Rolling Stock Maintenance management system to allow the transfer of train ID data to train locations in the yard signal control system tracking functions

25.18 Transition Tracks between Main Tracks and Yard Tracks

The tracks where trains transition between ATC mode of operation (main tracks) and Yard Mode shall be called Transition Tracks. Control of train movements between the Transition Tracks and the Yard Tracks shall be by means of the Yard Signal control system. Control of train movements between the main tracks and the Transition Tracks shall be by the main track ATC and ATC-ATS system.

The yard route logic controllers shall interface with the ATC Interlocking equipment to ensure continuity of route locking and prevention of head to head movements for train movements between the yards and Main Tracks in both directions.

Train mode transitions between ATC and Yard Modes are described in the *Automatic Train Control* chapter of these Design Criteria.

25.19 Maintenance of Infrastructure Yards

MOI yards will be divided into two sections:

- Transition Tracks that connect the Main Tracks with the Yard Tracks
- Yard Tracks

MOI yard Transition Tracks shall be equipped in a similar fashion to yard Transition Tracks. Main track standard equipment shall be installed on the Transition Tracks and signals shall be provided at both ends of the track(s). Routes between the Main Track and the Transition Tracks shall be equipped, protected, and controlled to Main Track standards. Routes between the Yard Tracks and the Transition Tracks shall be inhibited when MOI equipment is operating from a Yard Track to the Transition Track(s), conflicting train movements from the Main Track to the Transition Track(s) and from the MOI tracks to the Transition Tracks shall be prevented.

MOI Transition Tracks shall be supervised and controlled from the Operation Control Center and/or Regional Control Centers.

ATC equipped trains shall transition modes in the same manner on Transition Tracks for MOI yards as for other yards. Refer to the *Automatic Train Control* chapter of these Design Criteria.

Switches within the MOI yard will be hand operated and equipped with mechanical or electrical indicators of switch position. MOI tracks, with the exception of Transition Tracks, need not be track circuited or provided with axle counters.

Signals are required only to indicate safe movement between the Transition Tracks, the Main Tracks, and Yard Tracks in each direction. Signals are not required within the MOI Yard Tracks.

Chapter 26

Electromagnetic Compatibility and Interference

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Revision	Date	Description
0	07 Mar 12	Initial Release, R0

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Acronyms

ATC	Automatic Train Control
CCTV	Closed Circuit Television
CENELEC	European Committee for Electrotechnical Standardization
CHSTP	California High-Speed Train Project
COTS	Commercial Off-The-Shelf
CPUC	California Public Utilities Commission
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EMI/EMF	Electromagnetic Interference/Electromagnetic Field
FCC	Federal Communications Commission
GSM-R	Global System for Mobile Communications – Railway
HVAC	Heating, Ventilation, and Air Conditioning
IEEE	Institute of Electrical and Electronics Engineers
IG	Insulated Ground
NEC	National Electric Code
NFPA	National Fire Protection Association
OCS	Overhead Contact System
RF	Radio Frequency
rms	root mean square
RS	Rolling Stock
SCADA	Supervisory Control and Data Acquisition Subsystems
SRS	Signal Reference Structure
TES	Traction Electrification System
TPF	Traction Power Facility
UL	Underwriters Laboratories
UPS	Uninterruptible Power Supplies

26 Electromagnetic Compatibility and Interference

26.1 Scope

The Electromagnetic Compatibility (EMC) Program scope includes the following:

- Electromagnetic interactions and related design characteristics of equipment and facilities
- Electromagnetic interactions with equipment and facilities of system neighbors.

System equipment and facilities shall work with and not interfere with other system equipment and facilities as well as with neighbor equipment and facilities

The EMC design scope includes the following:

- Design aspects of the equipment and facilities which can electromagnetically interact with themselves, with other equipment and facilities, and with the equipment and facilities of system neighbors
- Specifically, Communications, Automatic Train Control (ATC), Traction Electrification System (TES), Rolling Stock (RS), and Station and Facility Equipment.

Existing neighbor equipment or facilities cannot be changed to resolve EMC issues, unless the project makes a specific agreement with the owner of the equipment or facilities.

EMC interaction scope includes the following:

- Design scope equipment and facilities
- Neighbor equipment and facilities.
- Electronic devices carried or used by passengers and staff in facilities and trains.

Neighbor equipment and facilities include the following:

- Electronic devices of neighbors and of California public safety, government, utility, and industrial staff
- Commercial, residential, and industrial buildings; airports; adjacent railroads, pipelines, and structures; and the industrial and commercial equipment used by the buildings and their occupants.

26.2 Regulations, Codes, Standards, and Guidelines

Refer to the *General* chapter for requirements pertaining to regulations, codes, and standards.

- Federal Communications Commission (FCC):

  - FCC, Part 15 Part 15 of Title 47 of the Code of Federal Regulations
- California Building Standards Commission: California Electrical Code (CEC)
- California Public Utilities Commission (CPUC) General Orders (GOs) and Decisions
  - CPUC GO No. 95 – Overhead Electric Line Construction
  - CPUC GO No. 131 – Rules Relating to the Planning and Construction of Electric Generation, Transmission/Power/Distribution Line Facilities and Substations Located in California
  - CPUC D93-11-013 – interim EMF Policy
  - CPUC D06-01-042 – updated EMF Policy
- National Fire Protection Association (NFPA) Codes and Standards
  - NFPA 70 – National Electric Code (NEC)
  - NFPA 780 – Standard for the Installation of Lightning Protection Systems
- European Committee for Electrotechnical Standardization (CENELEC) Standards
  - EN 50121-1, Railway applications – Electromagnetic Compatibility – Part 1: General
  - EN 50121-2, Railway applications – Electromagnetic Compatibility – Part 2: Emission of the whole railway system to the outside world
  - EN 50121-3-1, Railway applications – Electromagnetic compatibility – Part 3-1: Rolling stock – Train and complete vehicle
  - EN 50121-3-2, Railway applications – Electromagnetic compatibility – Part 3-2: Rolling stock – Apparatus
  - EN 50121-4, Railway applications – Electromagnetic Compatibility – Part 4: Emission and immunity of signaling and telecommunications apparatus
  - EN 50121-5, Railway applications - Electromagnetic compatibility – Part 5: emission and immunity of fixed power supply installations and apparatus
  - EN 50155, Railway applications – Electronic equipment used on rolling stock
  - EN 50238-1, Railway applications – Compatibility between rolling stock and train detection systems
  - EN 50238-2, Railway applications – Compatibility between rolling stock and train detection systems – Railway applications – Part 2: Compatibility with track circuits
  - EN 50238-3, Railway applications – Compatibility between rolling stock and train detection systems – Railway applications – Part 3: Compatibility with axle counters
  - EN 50388, Railway applications – Power supply and rolling stock – Technical criteria for the coordination between power supply (substation) and rolling stock to achieve interoperability

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  - EN 50500, Measurement procedures of magnetic field levels generated by electronic and electrical apparatus in the railway environment with respect to human exposure
- American Public Transportation Association (APTA) Standards, SS-E-10-98, Standard for the Development of an Electromagnetic Compatibility Program Plan
- American Railway Engineering and Maintenance-of-Way Association (AREMA) Communications and Signals Manual of Recommended Practice
- Federal Transit Administration (FTA)
  - UMTA-MA-06-0153-85-11, Radiated Interference in Rapid Transit Signaling Systems - Volume II: Suggested Test Procedures
  - UMTA-MA-06-0153-85-6 (also identified as UMTA-MA-06-0153-87-2), Conductive Interference in Rapid Transit Signaling Systems Volume II: Suggested Test Procedures
  - UMTA-MA-06-0153-85-8, Inductive Interference in Rapid Transit Signaling Systems - Volume II: Suggested Test Procedures
- Institute of Electrical and Electronics Engineers (IEEE) Standards
  - IEEE Std C95.1, IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 3 kHz - 300 GHz
  - IEEE Std C95.6, IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0 - 3 kHz
  - IEEE Std 1100, Recommended Practice for Powering and Grounding Electronic Equipment
  - IEEE Std 1143, IEEE Guide on Shielding Practice for Low Voltage Cables
  - IEEE Std 142, Recommended Practice for Grounding of Industrial and Commercial Power Systems
  - IEEE Std 518, IEEE Guide for the Installation of Electrical Equipment to Minimize Electrical Noise Inputs to Controllers from External Sources
  - IEEE Std 519, Recommended Practice and Requirements for Harmonic Control in Electrical Power Systems
  - IEEE Std 525, IEEE Guide for the Design and Installation of Cable Systems in Substations
  - IEEE Std C2, National Electrical Safety Code
- Architectural Electromagnetic Shielding Handbook, Leland H. Hemming, IEEE Press, 1992 and any revisions
- U.S. Department of Defense (USDOD) Standards: MIL-HDBK-419A, Grounding Bonding and Shielding for Electronic Equipment and Facilities (Volume I, Basic Theory, 1987)
- Pacific Gas & Electric Company Transmission Line EMF Design Guidelines, May 1994
- Southern California Edison EMF Design Guidelines For Electrical Facilities, September 2004

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- CPUC Summary, San Diego Gas and Electric, summary of EMF related activities of the CPUC, http://sdge.com/safety/electric/emf/emfActivities.shtml
- Federal Communications Commission (FCC) Reports
  - FCC OET-65, Evaluating Compliance with FCC Guidelines for Human Exposure to Radio frequency Electromagnetic Fields, FCC Office of Engineering and Technology Bulletin 65, Edition 97-01, August 1997
  - FCC OET-65c, Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields, FCC Office of Engineering and Technology Supplement C (Edition 01-01) to OET Bulletin 65 (Edition 97-01)

26.3 Description of Electromagnetic Compatibility Program and Electromagnetic Interference

The EMC Program objective is to achieve EMC between all EMC design scope and interaction scope equipment and facilities.

The EMC program shall ensure that Electromagnetic Interference (EMI) does not adversely affect the following:

- The safety or dependability of the system and service
- The health of passengers, staff, and neighbors
- The safety or dependability of neighbor equipment and facilities.

To meet the EMC Program objective, the EMC Program specifies the following:

- Activities and deliverables at each project stage and phase for the Electromagnetic Interference Project Management Team, Regional Consultants, equipment suppliers, construction contractors, and subcontractors
- Design guidelines, criteria, and methods
- EMC design requirements to be included in the procurement specifications of each affected system or piece of equipment and each affected construction contract
- EMC analyses and tests to demonstrate compliance with EMC requirements

26.4 General Design Requirements

Equipment and facilities shall be electromagnetically compatible with one another, with other system equipment and facilities, and with the equipment and facilities of neighbors.

The Contractor shall apply the EMC design criteria to all equipment, systems, and facilities:

- Communications
- Automatic Train Control
- Traction Electrification System
- Rolling Stock
- Station and Facility Equipment

26.5 Overview of EMC Design Criteria Categories

The EMC design criteria cover equipment, cable, grounding, facility and high power, motors and controllers, equipment rooms and location, emission and immunity limits, FCC type-accepted radio equipment, and human exposure. The following is an overview of EMC design criteria:

- **Cable** – Cables shall be designed with proper shielding, shield grounding, entry protection, and termination. Each cable may be grouped only with others with similar signal type and energy level. Each cable or group shall be segregated appropriately from other cable groups. Cable runs shall be placed in conduit, raceway, or duct as needed to provide segregation and prevent magnetic or electric coupling from high-energy sources. The Contractor shall use fiber optic cable where practical for EMC. Power cables shall be treated according to required practice for their voltage class.
- **Grounding** – Grounding shall conform to the listed standards, provide a suitable safety ground, and signal reference structure ground connections. Long adjacent fences and pipelines shall be regularly grounded or if not grounded, divided into insulated sections to prevent electric shock.
- **Equipment** – Equipment designs shall control emissions and enhance immunity. Design considerations shall include placement, enclosures, filters, modulation methods, interconnect design, and component characteristics.
- **Facility Power** – AC power for equipment shall be properly taken from separate feeder and branch circuits, isolated, regulated, backed up, and protected as required. AC power for remote trackside locations can be taken from the negative feeder by a dedicated transformer and disconnect, and filtered to protect supplied equipment. High-current power supply ac cables shall be run twisted together, in metal conduit where possible, to minimize magnetic coupling. Traction power cables shall be run with the smallest feasible separation of supply feed and return cables. Layout shall minimize the loop area of high current cables. Utility power distribution lines shall be routed and carried to system facilities following applicable electromagnetic interference/electromagnetic field (EMI/EMF) regulations and guidelines.

- **Motors and Controllers –** Motor starter or inverters shall be provided with suitable protection and line and load filtering to minimize harmonics, transients, and surges at start and stop. Wiring shall be by twisted and/or shielded cables in conduit as appropriate.
- **Equipment Rooms and Location –** Within physical constraints of planned facilities, equipment shall be located so that high power sources are physically separated as far as practical from the most susceptible equipment. Shielding shall be provided as needed.
- **Emission and Immunity Limits –** Equipment shall be designed and tested to conform to the selected emission and immunity limits. Commercial off-the-shelf (COTS) equipment shall meet the specified standards. Custom equipment shall meet the selected standards, which are FCC Part 15, EN 50121 series, and applicable standards. In cooperation with the adjacent railroads, the Contractor shall mitigate coupling of system 60 Hz power into track circuits of adjacent railroads. The Contractor shall coordinate with the operator of any airport adjacent the alignment to ensure EMC.
- **FCC Type-Accepted Radio Equipment –** Radio equipment shall be FCC-type approved. Frequencies for licensed radio equipment shall be coordinated within the system and with other California users. Equipment that transmits or receives on a specific frequency shall be coordinated with the established list of frequencies used by other equipment. Industrial, scientific, and medical device frequency band (ISM) equipment shall be FCC Type Accepted in the 2.4 or 5.8 GHz band. ISM design applications shall operate adequately with interference from other ISM band users.
- **Human Exposure** – Placement of radio transmit antennas shall result in human exposure to fields below limits. Traction electrification facilities shall be posted with signs alerting staff with implanted medical devices such as pacemakers of potentially hazardous electromagnetic field (EMF) levels.

26.6 Communications EMC Design Criteria

26.6.1 Equipment and EMC Considerations

Communications systems equipment is described in the *Communications* chapter. The equipment will consist of the following:

- Wayside communication systems connected by copper wires and by fiber optic cable. Examples include Supervisory Control and Data Acquisition Subsystems (SCADA), Closed Circuit Television (CCTV), data network, intercom and public address, telephone, security and access control, traction power control, and fire and life safety subsystems and functions.
- Wayside and onboard radio systems. Examples include ATC data and voice radio, operations and maintenance radio, voice and data; police, fire, and emergency public safety radio; Wifi and other unlicensed radio; and ATC radio such as 160 MHz, 220 MHz, and Global System for Mobile Communications - Railway.

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- Equipment includes cabinets and contents, control panels, displays, cables, conduits, ducts, raceways, enclosures, and antennas.

Cell phone service and passenger information and entertainment radio will be provided separately. They are not in the present scope.

Communication equipment EMC provisions shall ensure the following:

- Safe and dependable operation
- No interference with or from neighbors
- Compliance with human exposure limits

The following design criteria shall apply to communications systems and to the communication system interfaces with ATC, trains, traction power, and station systems and equipment:

- Cables and cable segregation
- Grounding
- Equipment design
- Facility power
- Motors and controllers
- Equipment rooms, cabinets, and locations
- Equipment emission and immunity limits
- Requirements for radios
- Human exposure limits.

The communication systems EMC design criteria are described in the following subsections.

26.6.2 Cable

26.6.2.1 General

The Contractor shall:

- Use optical interconnection cables wherever it is technically feasible and cost-effective. Optical connections between equipment and equipment locations are immune to EMI.
- Select, install, and connect electrical cables with proper shielding, shield grounding, conduit or duct protection, entry protection, routing, and termination to control EMI in copper electrical cables as described in this section.
- Electrical cable provisions shall comply with the National Electric Code (NEC) Chapter 2 (Wiring and Protection), Chapter 3 (Wiring Methods and Materials), Chapter 4 (Equipment

for General Use), Chapter 7 (Special Conditions) and Chapter 8 (Communication Systems), except to the extent other Design Criteria provisions specify otherwise.

26.6.2.2 Electrical Cable Categories

For EMC purposes, each cable shall be assigned to one of the cable categories in Table 26-1.

Table 26-1: Electromagnetic Compatibility Cable Categories

ID	Name	Examples, References, Comments
C1	Power at 600 V ac RMS or higher	115 kV feeder.
C2	Traction Power	25 kV ac traction power and return cables.
C3	Power at less than 600 V ac RMS	480 V ac, 120 V ac, Lighting Circuits, heating, ventilation and air conditioning (HVAC) motors, uninterruptible power supplies (UPS), etc.
C4	NEC Class 1 circuits	NEC Class 1 power limited circuits per NEC 725.41 (A), limited to less than 30 V and 1000 VA. NEC Class 1 remote-control and signaling circuits per NEC 725.21 (B), less than 600 V. Includes safety-critical signaling circuits such as fire alarm.
C5	NEC Class 2 and 3 circuits	Power sources for NEC Class 2 and Class 3 circuits per NEC 725.121, shall be limited per Chapter 9 Table 11(a) and Table 11(b).
C6	Unshielded twisted pair signal circuits	Telephone, speaker level audio output, Ethernet.
C7	Shielded signal circuits including shielded twisted pair, coax, and multi-axial cables	CCTV from camera to converter box, microphone and line level audio input, line level audio output.
C8	Leaky coax cable	Distributed communication antenna.
C9	Optical cable	Backbone Network, Local Area Network, CCTV camera feeds from converter box to comm. room.

26.6.2.3 Cable Separation Criteria

Cables in the same cable category may be run together in the same steel conduit, raceway, duct, or cable tray.

Cables in different cable categories shall not be run together in the same cable assembly, conduit, raceway, duct, or cable tray, without engineering justification documenting the specific cables, signals, and protections against EMI for the proposed combination. However, optical cables (C9) may be run together with any other cable.

Cables running parallel to the track shall be segregated in the cable troughs and duct banks according to cable category.

Wires carrying circuits belonging to a single cable category but which use different signal levels shall not be run together in the same cable, without engineering justification documenting the specific cables, signals, and protections against EMI for the proposed combination.

Where cables of dissimilar type, service, or signal level cross, the crossing of the cables and their conduits and raceways shall be perpendicular where practical.

Cable separation design shall conform to IEEE Standard 1100-2005, Recommended Practice for Powering and Grounding Electronic Equipment, Section 9.9.

26.6.2.4 Cable Shielding

The Contractor shall use shielded cables and steel conduits and ducts to protect components, circuits, and systems against the effects of undesirable external disturbing EMI sources. A cable shield can:

- Increase immunity and provide additional protection against interference to the enclosed circuits.
- Reduce emissions and provide additional reduction of the level of interference emitted by an enclosed circuit.

Wire and cable shielding and shield grounding design for electronic signals shall conform to IEEE Std 1100-2005, Sections 3.3, 4.9, 9.9, 10.2, and 10.4; and to IEEE Std 1143-1994, Guide on Shielding Practice, Section 7.

26.6.2.5 Cable Shield Grounding

The connections of cable shields and the connection of the shields to the grounding system determine the effectiveness of the shielding in mitigating EMI.

The Contractor shall specify and use a coordinated and consistent method for terminating and connecting cable shields to equipment. The method shall conform to these criteria. The Contractor shall document the specific provisions for cable shield grounding at the system and detail level as part of a Cable EMC Schedule. The Contractor shall ensure that the Cable EMC Schedule is fully implemented across the systems.

The general topology for shield connection to power supply ground shall conform to IEEE Std 1100-2005, Sections 8.5, 9.9, 10.2, and 10.4.

The Contractor shall properly terminate cable conductors, shield, and drain wire, if used, on the connector to prevent the inadvertent grounding of the shield or conductor connection via the connector shell to the equipment enclosure or to another unintended potential.

26.6.2.6 Conduit and Duct

The Contractor shall:

- Run specified cables in trackside ducts. Metal conduits or ducts for cables provide mechanical protection and electrical safety as well as additional electromagnetic isolation compared to physical separation of cables. Metal conduits and ducts increase the immunity of and decrease the emissions from enclosed circuits.
- Use steel conduit and ducts; do not use aluminum.
- Run cables in steel conduit or steel duct on any run that is outside of a single enclosure for any part of its route, except for cables in the trackside ducts and cables for which engineering justification documents the basis for the cables to be run out of conduit.

26.6.2.7 Conduit and Duct Bonding and Grounding

Metal conduit and duct can serve as an overall shield for cables carrying sensitive signals, and for cables carrying signals, which tend to emit EMI. To provide a shielding function, conduit and duct shall be grounded and bonded per the NEC Article 250 where not in conflict with the *Grounding and Bonding Requirements* chapter.

Hardware listed only by a nationally recognized testing laboratory such as Underwriters Laboratories (UL) shall be used to join and bond conduits and ducts to enclosures, including conduit fittings and EMI gaskets.

Fully coordinate insulated ground (IG) ac circuit conduit routing and connections with the grounding of the systems powered by insulated ground circuits. Refer to Section 26.6.3.6 for IG details.

26.6.2.8 Entry Protection

The Contractor shall provide the following:

- Room entry EMI impulse protection for wires entering an equipment room
- Enclosure entry EMI impulse protection for wires entering an equipment enclosure

The protection shall consider and be consistent with the cable type, the cable source, and the potential EMI hazards to be protected against. As noted above, cables entering an equipment room shall be enclosed in steel conduit unless the system designer provides specific technical justification for another entry protection method consistent with the above criteria.

Room entry and line entry impulse protection shall consist of line-to-line and/or line-to-ground protection, as appropriate, for each circuit type. Circuit protections on wires include combinations of lightning arrestors, transient suppressors, fuses, spark gaps, filters, ferrite beads and clamshells, etc.

26.6.2.9 Cable Termination

The Contractor shall terminate all impedance controlled cables, such as coax, with the proper impedance.

26.6.2.10 Circuit Loops

The Contractor shall:

- Minimize the area of circuit loops in which magnetic fields can couple.
- For high current circuits, run the feed and return conductors as closely together as feasible and minimize the length over which the feed and return cables are run separated from one another, to reduce the flux generating loop. To improve the immunity of signal circuits, use twisted pair cables.
- To minimize coupling between the flux generating loop and the signal circuit, maximize the distance between power cables and signal cables, and minimize the distance over which the signal cable runs near and parallel to the power cable.
- Ensure that design layout drawings have sufficient detail to show the physical routing of all conduits and cables, so that EMC compatibility can be designed and documented.

26.6.3 Grounding

26.6.3.1 General

The Contractor shall:

- Make equipment grounding provisions so all equipment has a suitable safety ground and so all equipment has suitable EMI-controlling signal ground and return connections.
- Provide a Grounding EMC Schedule and drawings detailing the specific design provisions for each equipment item and its grounding connections.
- Prepare an overall grounding diagram that defines the grounding scheme for each system and subsystem, the ac power (both non-insulated ground and insulated ground) circuits serving these systems, and the interconnection means and interconnection points of the grounding systems.

For safety grounding requirements, refer to the *Grounding and Bonding Requirements* chapter.

26.6.3.2 Grounding Categories

For EMC purposes, the Contractor shall use the grounding categories in Table 26-2 to categorize each ground connection. The Contractor shall apply these grounding categories to:

- Minimize the effects of electrical noise generated by system and neighboring electrical equipment.
- Minimize disturbing effects within directly affected control equipment and propagating effects on associated equipment, which might result from ground currents, fault currents, or nearby lightning strikes.
- Minimize the shock exposure potential which might appear on non-current-carrying equipment or conducting structures, in case an insulation failure energizes the enclosing

structure with a dangerous voltage. Proper grounding of equipment and conducting structures will minimize the shock hazard due to a power line insulation failure.

- Provide a discharge path for stray radio frequency (RF) energy.

Table 26-2: Grounding Categories

ID	Name	Examples, References, Comments
G1	Lightning protection ground	The building lightning protection ground shall connect to the power safety ground, at a single point per NFPA 780-2004: Standard for the Installation of Lightning Protection Systems.
G2	Power safety ground	Governed by the NEC Article 250
G3	Sensitive electronic equipment ground	The sensitive electronic equipment ground should connect by bonding to the power safety ground at only a single point.
G4	Signal reference structure (SRS) ground	G4 SRS ground configurations include grids and planes which provide a high-frequency common ground reference to which control and communications signals are referenced. A matrix ground mat in or under a sensitive equipment room is a typical SRS implementation. The SRS provides a better reference than a single G3 ground as it provides a lower impedance at high frequencies. If the connection from a G3 sensitive electronic equipment ground to the G2 power safety ground is long, higher impedance in the ground structure results in more electrical noise. A G4 SRS can resolve the problem.
G5	Traction power return	The traction power return and running rails are grounded at each Traction Power Facility (TPF) via a connection from the TPF return bus to the TPF ground grid. The running rails are also connected to the aerial ground wire and to the earth at impedance bond locations at intervals along the track.

The Contractor shall:

- Provide a direct, dedicated ground connection when connecting signal and communication ground circuits to a TPF ground grid.
- Identify, coordinate, keep separate, insulate, and appropriately connect the grounds in each of the ground categories in Table 26-2. Where necessary, identify special provisions for grounds in tunnels, trenches, at-grade ballasted or non-ballasted track, and aerial structures or bridges.
- Integrate and coordinate the lightning protection grounding system with the other grounding system designs.

Optical or other galvanic isolation of signals may be needed to create and maintain the separation of grounds.

26.6.3.3 Traction Power Return

The traction power return circuit shall be connected to the TPF ground grid at each TPF. In addition, the running rails shall be connected via impedance bonds to the earth and to the Aerial Ground Wire at intervals between TPF locations, to control step and touch voltage hazards.

For safety grounding requirements, refer to the *Grounding and Bonding Requirements* chapter.

26.6.3.4 Industry Standard for Powering and Grounding Electronic Equipment

The designs for powering and grounding electronic equipment shall conform to the applicable portions of the National Electric Code of IEEE Std 1100 and IEEE Std 142, as adapted for the system environment.

For equipment designs and connections, the Contractor shall use the specified techniques for powering and grounding electronic equipment.

Note that in the recommended power and grounding schemes, the "grounded conductor" refers to that leg of the circuit (usually the neutral) that is intentionally held at ground potential. The "grounded conductor" is part of the current-carrying circuit. The “grounding conductor” refers to the conductor(s) that connect(s) exposed metal parts of a device to ground; primarily for safety, secondarily for performance. The “grounding conductor” is not part of the current-carrying circuit.

26.6.3.5 Grounding Design Criteria

The Contractor shall:

- Use a safety grounding technique for equipment in racks per IEEE Std 1100-2005, Sections 3.3, 4.9, 8.5, 9.9, 10.2, and 10.4.
- Use a high frequency or RF grounding technique signals per IEEE Std 1100-2005, Sections 3.3, 4.6, 8.5, 9.9, 10.2, and 10.4.

The grounding system shall provide that when electronic equipment has a conducting connection to other devices within a structure that all interconnected devices be referenced at the same lightning protection ground (G1) to minimize possible lightning damage.

26.6.3.6 Insulated Ground Design Criteria

Sensitive equipment may use an NEC-compliant isolated ground to provide basic fault/personnel protection and to protect the equipment. These Design Criteria refer to the NEC-compliant isolated ground using the IEEE Std 1100 nomenclature, which is “insulated ground” (IG).

For IG connections for equipment in racks, modify the safety grounding configuration from that shown in IEEE Std 1100-2005, Figures 8-17 and 8-18, by placing a listed nonmetallic raceway fitting between the equipment rack and the conduit system, as shown in NEC Handbook

Exhibit 250.45. The configuration shall ensure that equipment and enclosures served by an IG power circuit are:

- Correctly and safety grounded at the IG location.
- Not inadvertently bonded to unintended non-insulated grounding paths.

26.6.4 Equipment Design

26.6.4.1 General

Equipment and system designs shall control emissions and increase EMI immunity. Design considerations include placement, enclosures, filters, interconnect design, component characteristics, and modulation methods.

The Contractor shall:

- Specify and implement design provisions for equipment placement, enclosures, filters, interconnect design, component characteristics, and modulation methods, for each equipment item, per the following subsections.
- Ensure that plan and elevation drawings show sufficient detail of the layout of equipment in each rack, the layout of racks within a room, and ancillary equipment within a room, so that EMC compatibility can be designed and documented.

26.6.4.2 Placement

The Contractor shall place high-power potential sources as far as practical from sensitive potential susceptible equipment, to minimize magnetic and electric field coupling between nearby pieces of equipment.

26.6.4.3 Enclosures

The Contractor shall:

- Install electronic equipment in a suitable EMI-Shielded Equipment Rack Cabinet.
- Protect signal and power lines entering enclosures from EMI by using appropriate cable termination techniques as well as proper conduit fittings, gaskets, etc.
- Enclose cables entering or leaving electronic enclosures in steel conduit, unless otherwise specifically justified by engineering documentation.
- A double-wall-shielded equipment enclosure may be necessary for sensitive equipment located near a powerful emissions source. In such cases, the inner enclosure shall be connected to the signal reference structure ground or IG, while the outer enclosure shall be connected to the power safety ground.
- Use shielded enclosures, metal ducts, and metal conduits to control the electromagnetic coupling between and from equipment and wiring.

Within enclosures, the Contractor shall:

- Carefully bundle, twist, shield, protect, route, and properly terminate high current cables such as motor cables, to minimize uncontrolled emissions. The Contractor shall ensure that the cable installation does not exceed the minimum bend radius for the cable.
- Connect low voltage cable shields to the appropriate low voltage ground at the source and, per IEEE Std 1100-2005, Sections 3.3 and 8.5 and IEEE Std 1143-1994, Section 7 to the receiver-end equipment.
- Use twisted pair and shielded cables, coax, or multiax for sensitive signals.
- Place inductive components perpendicularly to nearby susceptible components to minimize the exposure to stray flux.

26.6.4.4 Filters

The Contractor shall:

- Use appropriate low-pass filters on wired connections. Filters minimize conducted emissions from a piece of equipment into other pieces of equipment and improve the immunity of the equipment to conducted emissions on the connecting wires.
- Provide filters on power inputs and outputs to and from ac inverters and converters, transmitters, receivers, and signal circuits.
- Use supply suitable transient suppressors for relay contacts switching inductive loads, including relay and contactor coils.

26.6.4.5 Interconnect Design

The Contractor shall use appropriate techniques to minimize emission and maximize immunity of power and signal conductors, including the following:

- Arrange wires, cables, and conduits to physically separate signals with different signal type, voltage and energy levels.
- Separate and shield circuits carrying power, high level signals, and low level signals.
- Use balanced circuits with coordinated current return paths.
- Minimize the loop area between source and return conductors.
- Use photocouplers or optical fiber to galvanically isolate circuit potentials when needed.
- Shield all sensitive signal conductors in suitable electric and magnetic shielding structures using appropriate combinations of steel conduit and shielded cable.
- Connect shields to appropriate system ground at the high energy end.

The Contractor shall use the following:

- Matching networks to match transmission line and antenna systems to maximize performance and minimize loss and reduce EMI for controlled impedance circuits such as radio frequency signals
- Shielded cables that have shield coverage of at least 90 percent
- Guard shields to improve immunity as required for sensitive electronic circuits
- Optical cables, optically-isolated signals, or other galvanic isolation for connection between equipment enclosures, whenever practical
- Isolation transformers, chokes and/or isolators for sensitive audio, video, and data circuits as required

26.6.4.6 Component Characteristics

The Contractor shall select appropriate components to reduce EMI. These include the following:

- For power converters, such as UPS, dc-to-ac inverters, and variable speed motor drives, use inductor-capacitor line EMI filters on each power input and output, to reduce power frequency and switching harmonic currents and radiated emissions.
- Ferrite beads and clamshells reduce emissions from signal cables and mitigate line-to-ground (common mode) and line-to-line (differential mode) noise.
- LCD displays for computers. Do not use CRT displays.

26.6.4.7 Modulation Methods

The Contractor shall use a modulation method, which controls and minimizes the conducted, inductive, and radiated emissions of the equipment for all equipment that converts power from one frequency, voltage, or current level to another.

For each power converter, the Contractor shall provide a report, manufacturer's data sheet, or other technical data to describe the modulation methods used as well as the mitigation methods use to minimize EMI.

26.6.5 Facility Power

26.6.5.1 General Criteria

The Contractor shall:

- Take power for communication electronic circuits, heating, ventilation and air conditioning (HVAC) equipment, lighting, elevators and escalators, and other systems from separate branch circuits which are isolated, regulated, backed up, and protected as required. Facility power shall comply with the requirements of the NEC Chapter 2 (Wiring and Protection), Chapter 3 (Wiring Methods and Materials), and Chapter 4 (Equipment for General Use).
- Provide a Communications Power EMC Schedule and drawings detailing the specific design provisions for each equipment item and its power and UPS connections.

- Prepare overall power diagrams that define the power distribution scheme for each system and subsystem and show the ac power with both non-insulated ground and insulated ground circuits serving these systems.

26.6.5.2 High Power

The Contractor shall run high-current power ac cables, including phase, ground, and neutral conductors, with minimum loop size and conductor separation, physically separated from sensitive circuits, or if near sensitive circuits, twisted or in steel conduit.

26.6.5.3 Utility Power

The Contractor shall:

- Provide a power distribution design which controls potential effects of EMI generated by high power equipment on sensitive electronic equipment. Use separate transformers and distribution buses to ensure high power loads are separated from sensitive loads.
- Use the physical placement of power distribution equipment to increase the immunity of sensitive electronic equipment to EMI generated by high power equipment.
- Route utility power distribution lines to facilities following applicable EMI/EMF regulations and guidelines.

26.6.5.4 Grounding of Uninterruptible Power Supply Circuits

The Contractor shall follow IEEE Std 142-2007, Recommended Practice for Grounding of Industrial and Commercial Power Systems, Section 1.9.1, for UPS grounding arrangements.

26.6.5.5 Remote Powered Locations

Remote communication locations where utility power is not available may use power supplied from the Overhead Contact System (OCS) negative feeder, from a solar storage system or from another source.

Power at a remote location fed from the negative feeder shall be via a transformer, disconnect, and suitable filtering and power conditioning to protect connected equipment from the transients and harmonics present in the negative feeder.

The selected remote power supply shall make appropriate design provisions for cable, ground, shielding, filtering, and other EMC constraints.

26.6.6 Motors and Controllers

For motors and motor controllers used within the Communication Systems, such as for ventilation equipment, the following criteria shall apply:

- The Contractor shall provide a Motor and Controller EMC Schedule and drawings detailing the specific design provisions for each motor and controller of more than 1 hp.

- The Contractor shall provide each motor starter, controller, or inverter with suitable protection and line and load filtering to minimize transients and surges at start and stop. Provide twisted and/or shielded cables in conduit as appropriate.
- The Contractor shall run input power wires and cables to motors in steel conduit, locate input conductors as far as practical from sensitive equipment, and run wires from the output of the any UPS that powers motors in steel conduit.
- The Contractor shall use soft-start motor controllers or inverters to minimize conducted line transients caused by motor starts. When multiple motors are in a room, coordinate and delay the starting of the motors in a sequence to avoid the intense transient and line dip effects of all motors starting at once.

26.6.7 Equipment Rooms and Locations

26.6.7.1 Location

The Contractor shall:

- Within the physical constraints of the planned facilities, locate equipment so that high-power sources are physically separated as far as practical from susceptible equipment and cables.
- Where communication equipment, radio, ATC, and similar rooms are near traction power transformers, HVAC motors, or other high current systems, locate the susceptible equipment as far as practical from the stray magnetic fields generated by the transformers, motors, and power cables.
- Preferably, locate high-current equipment and cables in rooms that are not adjacent (either vertically or horizontally) to rooms with sensitive and susceptible equipment. The Contractor shall run all input power cables to high-current equipment in steel conduit.
- Maximize distance between EMI emitter rooms and EMI susceptible receiver rooms. The Contractor shall lay out the equipment rooms with high current equipment at one end of a suite of rooms and susceptible equipment at the other (far) end of the suite of rooms. To the extent practical, for example, the Contractor shall locate rooms so that they start from the left in a hypothetical plan:
  - Traction power, HVAC, or other high current rooms would be at the leftmost position (room 1)
  - The electrical distribution room (room 2) would be adjacent to and to the right of room 1.
  - The UPS room (room 3) would be adjacent to and to the right of room 2.
  - The communications rooms would be adjacent to and to the right of room 3.

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26.6.7.2 Equipment Room Shielding

When architectural or structural constraints do not allow room locations and cable and equipment placement per Section 26.6.7.1 and when required by the characteristics of sensitive equipment installed in a room, the Contractor shall use architectural shielding in the sensitive room to mitigate the electric and magnetic fields from the high-current equipment. Architectural shielding materials include steel sheet and steel mesh wall linings; other shielding wall linings such as sheet copper, copper mesh, or conductive polyamide mesh; EMI-shielded doors, windows, access panels, and air ventilation panels; EMI-conductive systems; shielding components; shielding laminates; and EMI-shielded equipment racks.

26.6.8 Equipment Emission and Immunity Limits

Typical rail and general-purpose communication systems make broad use of commercial-off-the-shelf (COTS) equipment. COTS equipment shall meet FCC regulations and other EMC standards governing emissions and immunity. Manufacturers of COTS equipment shall guarantee that their equipment meets required regulations and selected published standards, but they will generally not test to confirm or modify their equipment to meet standards other than the required and selected published ones.

All electrical and electronic equipment shall conform to the electromagnetic emission and immunity limits and related requirements in the following subsections.

Each item of electrical or electronic equipment shall be certified and documented to conform to the applicable limits. For equipment that is non-COTS, this documentation shall include a test report, manufacturer's performance data, and acceptance certificates from a qualified test laboratory. Each equipment supplier shall demonstrate and document compliance of each item.

26.6.8.1 Commercial-Off-The-Shelf Communications Equipment Emission Limits

COTS equipment that is not radio transmission equipment shall meet the following conducted and radiated emission requirements of Part 15 of Title 46 of the Code of Federal Regulation (FCC Part 15), sub-part B:

- Section 15.107(b), Conducted Limits, Class A digital devices
- Section 15.109(b), Radiated Limits, Class A digital devices

FCC Part 15.3(h) defines Class A devices as digital devices that are marketed for commercial, industrial, or business use, not for use in general public or home applications.

FCC Part 15 does not provide immunity limits.

COTS non-radio equipment shall be proven in similar service and shall have a Certification or a Declaration of Conformity per FCC Part 15, sub-part B, Class A devices. For such equipment, the Contractor shall provide documentation of the suitability or test results. Suitability considerations are the following:

- The equipment is COTS.
- The equipment is suited for the planned application.
- The equipment has Certification or a Declaration of Conformity per FCC Part 15, sub-part B, Class A device regulations.

A set of COTS equipment, when installed in a compliant and correct manner in an adequate shielded equipment rack, can be treated as a single item of COTS equipment for the purposes of tests and documentation. However, treatment of a shielded rack of equipment as COTS does not relieve the supplier of responsibility to achieve and document electromagnetic compatibility for the equipment rack and all the equipment in it.

26.6.8.2 Non-COTS Communications Equipment Emissions and Immunity

Non-COTS communications equipment radiated and conducted immunity limits shall conform to EN 50121-4, Railway applications - Electromagnetic Compatibility, Part 4: Emission and immunity of signaling and telecommunications apparatus.

Per EN 50121-4, the non-COTS communications equipment radiated and conducted emission limits shall conform to EN 61000-6-4, Electromagnetic Compatibility, Part 6-4: Generic Standards - Emission Standard for industrial environments

Each communications equipment supplier shall provide equipment that conforms to the applicable limits, as well as test certification or documentation demonstrating compliance.

In addition, FCC Part 15 governs both COTS and non-COTS communications equipment radiated and conducted emissions, other than for vehicle equipment. FCC limits are more restrictive than EN 50121-4 limits.

Non-COTS communication equipment immunity limits for electrostatic discharge, fast transients, and surges shall conform to EN 50121-4, Railway applications - Electromagnetic Compatibility, Part 4: Emission and immunity of signaling and telecommunications apparatus.

26.6.9 FCC Type Accepted Radio Equipment

Radio equipment shall be FCC Type Accepted. Frequencies for licensed radio equipment shall be coordinated with the project needs and as part of the coordination effort with other nearby users.

For FCC Type Accepted radio equipment, the Contractor shall provide a Radio EMC Schedule and drawings detailing the specific design provisions for each FCC Type Accepted radio.

For radio transmission equipment which has been proven in similar service and which has received Type Acceptance per applicable FCC Part 15 regulations, the suppliers shall document its suitability, demonstrating the following:

- The radio transmission equipment is suited for the planned application.

- The radio transmission equipment has received FCC Part 15 Type Acceptance.

26.6.9.1 Radio Equipment Design Considerations

The Contractor shall develop a detailed frequency and intermodulation analysis and report for each radio system, as part of the Radio EMC Schedule. The report shall cover modulation methods and the following:

- Transmission Lines – Use transmission lines, with proper terminating impedances, and matched circuits in RF applications.
- Antenna Placement – Place antennas to consider radio propagation factors for reliable operation, and also human exposure levels for any antennas which share an environment with patrons, staff, and neighbors.
- Intermodulation Suppression – Perform a frequency and interference analysis during the design phase for sites with more than one transmitter and receiver. As appropriate, apply the following:
  - Cavity filters to attenuate interfering signals from co located transmission equipment
  - Isolators to further suppress intermodulation
  - Proper selection of antenna combiners and multi-couplers and segregation of high and low power transmission equipment

26.6.9.2 ISM Equipment

Industrial, scientific and medical device frequency band (ISM) equipment shall be FCC type-accepted ISM band equipment in either the 2.4 GHz or 5.8 GHz ISM band. ISM design applications shall provide acceptable performance when interference from other ISM band users is present from many other mobile and fixed sources.

26.6.9.3 Radio System Frequency Coordination

The Contractor shall:

- Use frequency coordination to minimize EMI. Frequency coordination shall consist of coordinating the transmission or emission frequencies and the reception or susceptible frequencies of all equipment with frequencies already in use in the system and by neighbors.
- Coordinate equipment that transmits or receives on a specific frequency with the list of frequency bands used by other equipment.

26.6.10 Human Exposure to Electromagnetic Fields

The Contractor shall place radio transmit antennas and design the connected radio systems so that human exposure is below the applicable specification limits for EMF in and around the project area.

The CPUC EMF Policy in Decision 06-01-042 states:

- Health hazards from exposures to EMF have not been established.
- State and federal public health regulatory agencies have determined that setting numeric exposure limits is not appropriate.
- Existing no-cost and low-cost precautionary-based EMF policy should be continued.

The IEEE developed a set of internationally recognized standards to achieve the safe use of electromagnetic energy in the range of 0 Hz to 300 GHz relative to the potential hazards from exposure of such energy to man, volatile materials, and explosive devices. In compliance with the CPUC decision and international practice, the system EMC Plan (EMCP) established EMF exposure limits in and around the system per the IEEE standards:

- IEEE Standard C95.6-2002 – IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0-3 kHz [IEEE Std C95.6]
- IEEE Standard C95.1-2005 – IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz [IEEE Std C95.1]

The IEEE standards and these criteria establish Maximum Permissible Exposure (MPE) limits for the general population and authorized people in controlled environments. Only workers, contractors, and other authorized personnel may be in the controlled environments, such as in equipment rooms, or along the Authority's right-of-way near the tracks. The MPE limits recognize that workers and others in these controlled environments have the knowledge to minimize the duration or extent of exposure to the higher levels that may present.

The magnetic field MPE limits for general public and controlled environments shall conform to IEEE Std C95.6 Table 2 and IEEE Std C95.1 Tables 2, 8, and 9. The limit for the general public at 60 Hz is 9.0 G.

The static electric field MPE limits for general public and controlled environments shall conform to the IEEE Std C95.1 Table 4, 8, and 9 and IEEE Std C95.6 Table 4.

The propagating EMF MPE limits for general public and controlled environments shall conform to the IEEE Std C95.1 Table 8 and 9.

The MPE limits in the cited revisions of the standards shall apply unless the Contractor establishes that a newer revision of the Standard is applicable and that the newer revision of the Standard provides adequate protection to people near the tracks.

26.7 Automatic Train Control EMC Design Criteria

26.7.1 Equipment and EMC Considerations

26.7.1.1 Automatic Train Control Equipment

ATC equipment are described in the *Automatic Train Control* chapter. The equipment will consist of the following:

- Wayside ATC systems connected by copper wires and by fiber optic cable. Examples include wayside control units; ATC radio units including Global System for Mobile Communications - Railway, Wifi, 160 MHz, and/or 220 MHz; trackside signals; switches, and hazard detectors; track circuits for train detection, train communication, and/or broken rail detection; transponders; OCC/RCC facilities, ATC SCADA, ATC workstations and display units; ATC data network; and support subsystems and functions.
- Trainborne systems. Examples include onboard ATC unit, ATC radio unit, Driver's display unit, tachometers and transponder sensors, ATC onboard data radio, and support subsystems and functions.
- Cabinets and contents, control panels, displays, cables, conduits, ducts, raceways, enclosures, and antennas.

Depending on the selected ATC technology, data radio communication between onboard and wayside control units may provide ATC data and functions, or coded track circuits may provide the equivalent function. In either case, the ATC equipment will include track circuits at least to provide broken rail detection. The ATC equipment will probably include track-mounted transponders, train-mounted transponder interrogators, and track and train auxiliary data radio equipment.

26.7.1.2 EMC Considerations

ATC equipment shall conform to EMC design criteria. ATC equipment EMC provisions shall ensure the following:

- Safe and dependable operation
- No interference with or from neighbors
- Compliance with human exposure limits to magnetic and electric fields

Track circuits shall have specified and demonstrated immunity to train-conducted and inductive emissions. Train-conducted emissions will include 60 Hz power frequency harmonics with significant levels at power harmonics across the audio frequency band. Train propulsion design criteria developed in coordination with the ATC system supplier shall control the amplitude of higher order, higher amplitude 60 Hz power frequency harmonics, and their potential impact on track circuits.

ATC equipment shall conform to electrical safety requirements.

ATC equipment shall provide safety-critical functions with the documented assurance that unsafe failures are controlled to an acceptable limit.

Design and maintenance provisions shall ensure that EMI cannot compromise the safety level of operations achieved by the ATC system.

ATC equipment generally does not use COTS equipment for safety-critical functions. ATC suppliers shall document the achieved level of compliance of their equipment to designated EMC standards.

The following design criteria apply to the ATC system and its interfaces with other systems:

- Cables and cable segregation
- Grounding
- Equipment design
- Facility power
- Motors and controllers
- Equipment rooms and locations
- Equipment emission and immunity limits
- Requirements for radios
- Human exposure limits

The ATC system EMC design criteria are described in following subsections.

26.7.1.3 EMC with Adjacent Railroads

Freight and commuter railroads including the Union Pacific Railroad and the BNSF Railway and electric railroads including Bay Area Rapid Transit and Santa Clara Valley Transportation Authority run adjacent to the alignment for long sections. On the tracks, 60 Hz traction power for high-speed trains will flow in the OCS, running rails, and in the earth, at 750 A or more per train. The EMF of the traction power system will couple some 60 Hz traction power current into the tracks of adjacent railways. High frequency currents may also couple into adjacent railroad communications equipment.

Where an adjacent railroad parallels the alignment for many miles, the induced voltage and current in the adjacent railroad tracks may interfere with the normal operation of the adjacent railroad signaling system, depending on the specific track circuit equipment in service on the adjacent railroad.

The Contractor shall work with the engineering department of adjacent railroads that parallel the alignment, to assess the specific track signal and communication equipment in use on

nearby sections, determine potential impacts of EMFs and radio frequency interference on the adjacent railroad equipment, and make suitable design provisions to prevent interference. Design provisions may include replacement of specific track circuit types with other types developed for operation on or near electric railways, providing filters for sensitive communication equipment, and potentially relocation or reorientation of radio antennas.

26.7.2 Cable

26.7.2.1 General

The Contractor shall:

- Use optical interconnection cables wherever it is technically feasible and cost-effective. Optical connections between equipment and equipment locations are immune to EMI.
- Select, install, and connect electrical cables with proper shielding, shield grounding, conduit or duct protection, entry protection, routing, and termination to control EMI in copper electrical cables as described in this section.

Electrical cable provisions shall comply with the NEC Chapter 2 (Wiring and Protection), Chapter 3 (Wiring Methods and Materials), Chapter 4 (Equipment for General Use), Chapter 7 (Special Conditions), and Chapter 8 (Communication Systems), except to the extent other Design Criteria provisions specify otherwise.

26.7.2.2 ATC System Cables

Equipment-specific EMC design criteria shall apply for specialized ATC system cables, including for the following:

- Cables from equipment rooms to wayside track circuit equipment; track switches and signals; transponders or balises
- Cables for ATC equipment onboard RS, including for power, RS interfaces, antennas, trainlines, and networks

26.7.2.3 Electrical Cable Categories

For EMC purposes, each cable shall be assigned to one of the cable categories in Table 26-3.

Table 26-3: Electromagnetic Compatibility Cable Categories

ID	Name	Examples, References, Comments
C1	Power at 600 V ac RMS or higher	115 kV feeder.
C2	Traction Power	25 kV ac traction power and return cables.
C3	Power at less than 600 V ac RMS	480 V ac, 120 V ac, Lighting Circuits, HVAC motors, UPS, etc.
C4	NEC Class 1 circuits	NEC Class 1 power limited circuits per NEC 725.41 (A), limited to less than 30 V and 1000 VA. NEC Class 1 remote-control and signaling circuits per NEC 725.21 (B), less than 600 V. Includes safety-critical signaling circuits such as fire alarm.
C5	NEC Class 2 and 3 circuits	Power sources for NEC Class 2 and Class 3 circuits per NEC 725.121, shall be limited per Chapter 9 Table 11(a) and Table 11(b).
C6	Unshielded twisted pair signal circuits	Telephone, speaker level audio output, Ethernet.
C7	Shielded signal circuits including shielded twisted pair, coax, and multi-axial cables	CCTV from camera to converter box, microphone and line level audio input, line level audio output.
C8	Leaky coax cable	Distributed communication antenna.
C9	Optical cable	Backbone network, local area network.

26.7.2.4 Cable Separation Criteria

Cables in the same cable category may be run together in the same steel conduit, raceway, duct, or cable tray.

Cables in different cable categories shall not be run together in the same cable assembly, conduit, raceway, duct, or cable tray, without engineering justification documenting the specific cables, signals, and protections against EMI for the proposed combination. However, optical cables (C9) may be run together with any other cable.

Cables running parallel to the track shall be segregated in the cable troughs and duct banks according to cable category.

Wires carrying circuits belonging to a single cable category, but which use different signal levels, shall not be run together in the same cable without engineering justification documenting the specific cables, signals, and protections against EMI for the proposed combination.

Where cables of dissimilar type, service, or signal level cross, the crossing of the cables and their conduits and raceways shall be perpendicular where practical.

Cable separation design shall conform to IEEE Std 1100-2005, Recommended Practice for Powering and Grounding Electronic Equipment, Section 9.9.

26.7.2.5 Cable Shielding

The Contractor shall use shielded cables and steel conduits and ducts to protect components, circuits, and systems against the effects of undesirable external disturbing EMI sources. A cable shield can:

- Increase immunity and provide additional protection against interference to the enclosed circuits.
- Reduce emissions and provide additional reduction of the level of interference emitted by an enclosed circuit.

Wire and cable shielding and shield grounding design shall conform to IEEE Std 1100-2005, Sections 3.3, 4.9, 9.9, 10.2, and 10.4; and to IEEE Std 1143-1994, Guide on Shielding Practice, Section 7.

Special considerations apply to signal control and lighting cables and switch control cables which connect to track signals and switches and run parallel to the track. Shielding and conduit non-continuity for track circuit signal cables shall comply with the guidelines provided in the *Grounding and Bonding Requirements* chapter, Signal Cables section: "Signal control or lighting cables and switch cables shall not have metallic shielding. Metallic messenger or duct shall not be used in any way that could cause an electrical interconnection between signals or signal structures and signal equipment housings." This criterion does not apply when otherwise directed by equipment-specific design criteria such as noted in Section 26.7.2.2.

26.7.2.6 Cable Shield Grounding

The connections of cable shields and the connection of the shields to the grounding system determine the effectiveness of the shielding in mitigating EMI.

Specify and use a coordinated and consistent method for terminating and connecting cable shields to equipment. The method shall conform to these criteria. The Contractor shall document the specific provisions for cable shield grounding at the system and detail level as part of a Cable EMC Schedule. The Contractor shall ensure that the Cable EMC Schedule is fully implemented across all systems.

The general topology for shield connection to power supply ground shall conform to IEEE Std 1100-2005, Sections 8.5, 9.9, 10.2, and 10.4.

The Contractor shall properly terminate cable conductors, shield, and drain wire, if used, on the connector to prevent the inadvertent grounding of the shield or conductor connection via the connector shell to the equipment enclosure or to another unintended potential.

26.7.2.7 Conduit and Duct

The Contractor shall:

- Run specified cables in trackside ducts. Metal conduits or ducts for cables provide mechanical protection and electrical safety as well as additional electromagnetic isolation compared to physical separation of cables. Metal conduits and ducts increase the immunity of and decrease the emissions from enclosed circuits.
- Use steel conduit and ducts; do not use aluminum.
- Run cables in steel conduit or steel duct on any run that is outside of a single enclosure for any part of its route, except for cables in the trackside ducts, for wayside signal cables as otherwise specifically required, and for other cables for which engineering justification documents the basis for the cables to be run out of conduit.

26.7.2.8 Conduit and Duct Bonding and Grounding

Metal conduit and duct can serve as an overall shield for cables carrying sensitive signals, and for cables carrying signals which tend to emit EMI. To provide a shielding function, conduit and duct shall be grounded and bonded per the NEC Article 250 where not in conflict with the *Grounding and Bonding Requirements* chapter.

Only hardware listed by a nationally recognized testing laboratory such as UL shall be used to join and bond conduits and ducts to enclosures, including conduit fittings and EMI gaskets.

Fully coordinate IG ac circuit conduit routing and connections with the grounding of the systems powered by insulated ground circuits. Refer to Section 26.7.3.6 for IG details.

26.7.2.9 Entry Protection

The Contractor shall provide the following:

- Room entry EMI impulse protection for wires entering an equipment room
- Enclosure entry EMI impulse protection for wires entering an equipment enclosure

The protection shall consider and be consistent with the cable type, the cable source, and the potential EMI hazards to be protected against. As noted above, cables entering an equipment room shall be enclosed in steel conduit unless the system designer provides specific technical justification for another entry protection method consistent with the above criteria.

Room entry and line entry impulse protection shall consist of line-to-line and/or line-to-ground protection, as appropriate, for each circuit type. Circuit protections on wires include combinations of lightning arrestors, transient suppressors, fuses, spark gaps, filters, ferrite beads and clamshells, etc.

26.7.2.10 Cable Termination

The Contractor shall terminate all impedance controlled cables, such as coax, with the proper impedance.

26.7.2.11 Circuit Loops

The Contractor shall:

- Minimize the area of circuit loops in which magnetic fields can couple.
- For high current circuits, run the feed and return conductors as closely together as feasible and minimize the length over which the feed and return cables are run separated from one another, to reduce the flux generating loop. To improve the immunity of signal circuits, the Contractor shall use twisted pair cables.
- To minimize coupling between the flux generating loop and the signal circuit, maximize the distance between power cables and signal cables, and minimize the distance over which the signal cable runs near and parallel to the power cable.
- Ensure that design layout drawings have sufficient detail to show the physical routing of all conduits and cables, so that EMC compatibility can be designed and documented.

26.7.3 Grounding

26.7.3.1 General

The Contractor shall:

- Make ATC equipment grounding provisions so all equipment has a suitable safety ground and all equipment has suitable EMI-controlling ATC ground and return connections.
- Provide an ATC Grounding EMC Schedule and drawings, which detail the specific design provisions for each equipment item and its grounding connections.
- Prepare an overall grounding diagram that defines the grounding scheme for each system and subsystem, the ac power (both non-insulated ground and insulated ground) circuits serving these systems, and the interconnection means and interconnection points of the grounding systems.

The *Grounding and Bonding Requirements* chapter contains specific criteria for the following:

- Grounding ATC equipment
- Grounding track circuits and other ATC equipment. The track circuit type will determine the grounding provisions for running rails.

Special considerations apply to signal control and lighting cables and switch cables which run parallel to the track. Shielding and conduit non-continuity for signal control and lighting cables and switch cables shall comply with the guidance in the *Grounding and Bonding Requirements* chapter, Signal Cables section: "Signal control or lighting cables and switch cables shall not

have metallic shielding. Metallic messenger or duct shall not be used in any way that could cause an electrical interconnection between signals or signal structures and signal equipment housings."

26.7.3.2 Grounding Categories

For EMC purposes, the Contractor shall use the grounding categories in Table 26-4 to categorize each ground connection and apply these grounding categories to:

- Minimize the effects of electrical noise generated by all equipment and by neighboring electrical equipment.
- Minimize disturbing effects within directly affected control equipment and propagating effects on associated equipment, which might result from ground currents, fault currents, or nearby lightning strikes.
- Minimize the shock exposure potential which might appear on non-current-carrying equipment or conducting structures, in case an insulation failure energizes the enclosing structure with a dangerous voltage. Proper grounding of equipment and conducting structures will minimize the shock hazard due to a power line insulation failure.
- Provide a discharge path for stray RF energy.

Table 26-4: Grounding Categories

ID	Name	Examples, References, Comments
G1	Lightning protection ground	The building lightning protection ground shall connect to the power safety ground, at a single point per NFPA 780-2004: Standard for the Installation of Lightning Protection Systems.
G2	Power safety ground	Governed by the NEC Article 250.
G3	Sensitive electronic equipment ground	The sensitive electronic equipment ground should connect by bonding the to the power safety ground at only a single point.
G4	Signal reference structure (SRS) ground	G4 SRS ground configurations include grids and planes which provide a high-frequency common ground reference to which control and communications signals are referenced. A matrix ground mat in or under a sensitive equipment room is a typical SRS implementation. The SRS provides a better reference than a single G3 ground as it provides a lower impedance at high frequencies. If the connection from the G3 sensitive electronic equipment ground to the G2 power safety ground is long, higher impedance in the ground structure results in more electrical noise. A G4 SRS can resolve the problem.

G5	Traction power return	The traction power return and running rails are grounded at each TPF via a connection from to the TPF return bus to the TPF ground grid. The running rails are also connected to the aerial ground wire and to the earth at impedance bond locations at intervals along the track.

The Contractor shall:

- Provide a direct, dedicated ground connection when connecting ATC and communication ground circuits to a TPF ground grid.
- Identify, coordinate, keep separate, insulate, and appropriately connect the grounds in each of the ground categories in Table 26-4. Where necessary, identify special provisions for grounds in tunnels, trenches, at-grade ballasted or non-ballasted track, and aerial structures or bridges.
- Integrate and coordinate the lightning protection grounding system with the other grounding system designs.

Optical or other galvanic isolation of signals may be needed to create and maintain the separation of grounds.

26.7.3.3 Traction Power Return

As noted in the following section on traction power, the traction power return circuit shall be connected to the TPF ground grid at each TPF. In addition, the running rails shall be connected via impedance bonds to the earth and to the Aerial Ground Wire at intervals between supply station locations, to control step and touch voltage hazards.

Refer to the *Grounding and Bonding Requirements* chapter.

26.7.3.4 Industry Standard for Powering and Grounding Electronic Equipment

The designs for powering and grounding ATC equipment shall conform to the applicable portions of the National Electric Code, of IEEE Std 1100, and of IEEE Std 142, as adapted for the environment.

For equipment designs and connections, the Contractor shall use the specified techniques for powering and grounding electronic equipment.

Note that in the recommended power and grounding schemes, the "grounded conductor" refers to that leg of the circuit (usually the neutral) that is intentionally held at ground potential. The “grounded conductor” is part of the current-carrying circuit. The “grounding conductor” refers to the conductor(s) that connect(s) exposed metal parts of a device to ground; primarily for safety, secondarily for performance. The “grounding conductor” is not part of the current-carrying circuit.

26.7.3.5 Grounding Design Criteria

The Contractor shall use the following:

- A safety grounding technique for equipment in racks per IEEE Std 1100-2005, Sections 3.3, 4.9, 8.5, 9.9, 10.2, and 10.4.
- A high frequency or RF grounding technique signals per IEEE Std 1100-2005, 3.3, 4.6, 8.5, 9.9, 10.2, and 10.4.

The grounding system shall provide that when electronic equipment has a conducting connection to other devices within a structure that all interconnected devices be referenced at the same lightning protection ground (G1) to minimize possible lightning damage.

26.7.3.6 Insulated Ground Design Criteria

Sensitive ATC equipment may use an NEC-compliant isolated ground to provide basic fault/personnel protection and to protect the equipment. These Design Criteria refer to the NEC-compliant isolated ground using the IEEE Std 1100 nomenclature, which is “insulated ground” (IG).

For IG connections for equipment in racks, the Contractor shall modify the safety grounding configuration from that shown in IEEE Std 1100-2005, Figures 8-17 and 8-18, by placing a listed nonmetallic raceway fitting between the equipment rack and the conduit system, as shown in NEC Handbook Exhibit 250.45. The configuration shall ensure that equipment and enclosures served by an IG power circuit are:

- Correctly and safety grounded at the IG location.
- Not inadvertently bonded to unintended non-insulated grounding paths.

26.7.4 Equipment Design

26.7.4.1 General

Equipment and system designs shall control emissions and increase EMI immunity. Design considerations include placement, enclosures, filters, interconnect design, component characteristics, and modulation methods.

The Contractor shall specify and implement design provisions for equipment placement, enclosures, filters, interconnect design, component characteristics, and modulation methods, for each equipment item, per the following subsections.

The Contractor shall ensure that plan and elevation drawings show sufficient detail of the layout of equipment in each rack, the layout of racks within a room, and ancillary equipment within a room, so that EMC compatibility can be designed and documented.

26.7.4.2 Power Frequency Track Circuits

Because the system will use 60 Hz traction power, the use of power frequency track circuits at 60 Hz or below is not permitted.

26.7.4.3 Placement

The Contractor shall place high power potential sources as far as practical from sensitive potential susceptible equipment, to minimize magnetic and electric field coupling between nearby pieces of equipment.

26.7.4.4 Enclosures

The Contractor shall:

- Install ATC electronic equipment in a suitable EMI-Shielded Equipment Rack Cabinet.
- Protect signal and power lines entering enclosures from EMI by using appropriate cable termination techniques as well as proper conduit fittings, gaskets, etc.
- Enclose cables entering or leaving electronic enclosures in steel conduit, unless otherwise specifically justified by engineering documentation.
- A double wall shielded equipment enclosure may be necessary for sensitive equipment located near a powerful emissions source. In such cases, the inner enclosure shall be connected to the signal reference structure ground or IG, while the outer enclosure shall be connected to the power safety ground.
- Use shielded enclosures, metal ducts, and metal conduits to control the electromagnetic coupling between and from equipment and wiring.
- Within enclosures:
  - Carefully bundle, twist, shield, protect, route, and properly terminate high current cables such as motor cables, to minimize uncontrolled emissions. Ensure that the cable installation does not exceed the minimum bend radius for the cable.
  - Connect low voltage cable shields to the appropriate low voltage ground at the source and, per IEEE Std 1100-2005, Sections 3.3 and 8.5 and IEEE Std 1143-1994, Section 7, to the receiver-end equipment.
  - Use twisted pair and shielded cables, coax, or multiax for sensitive signals.
  - Place inductive components perpendicularly to nearby susceptible components to minimize the exposure to stray flux.

26.7.4.5 Filters

The Contractor shall:

- Use appropriate low-pass filters on wired connections. Filters minimize conducted emissions from a piece of equipment into other pieces of equipment and improve the immunity of the equipment to conducted emissions on the connecting wires.

- Provide filters on power inputs and outputs to and from ac inverters and converters, transmitters, receivers, and signal circuits.
- Use supply suitable transient suppressors for relay contacts switching inductive loads, including relay and contactor coils.

26.7.4.6 Interconnect Design

The Contractor shall use appropriate techniques to minimize emission and maximize immunity of power and signal conductors, including the following:

- Arrange wires, cables, and conduits to physically separate signals with different signal type, voltage and energy levels
- Separate and shield circuits carrying power, high level signals, and low level signals
- Use balanced circuits with coordinated current return paths
- Minimize the loop area between source and return conductors
- Use photocouplers or optical fibers to galvanically isolate circuit potentials when needed.
- Shield all sensitive signal conductors in suitable electric and magnetic shielding structures using appropriate combinations of steel conduit and shielded cable.
- Connect shields to appropriate system ground at the high energy end
- Use matching networks to match transmission line and antenna systems to maximize performance and minimize loss and reduce EMI for controlled impedance circuits such as radio frequency signals.
- Use shielded cables that have shield coverage of at least 90 percent
- Use guard shields to improve immunity as required for sensitive electronic circuits.
- Use optical cables, optically-isolated signals, or other galvanic isolation for connection between equipment enclosures, whenever practical.
- Use isolation transformers, chokes and/or isolators for sensitive audio, video, and data circuits as required.

26.7.4.7 Component Characteristics

The Contractor shall select appropriate components to reduce EMI. These include the following:

- For power converters, such as UPS, dc-to-ac inverters, and variable speed motor drives, use inductor-capacitor line EMI filters on each power input and output, to reduce power frequency and switching harmonic currents and radiated emissions.
- Ferrite beads and clamshells reduce emissions from signal cables and mitigate line-to-ground (common mode) and line-to-line (differential mode) noise.
- Use LCD displays for computers. Do not use CRT displays.

26.7.4.8 Modulation Methods

The Contractor shall:

- Use a modulation method which controls and minimizes the conducted, inductive, and radiated emissions of the equipment for all equipment which converts power from one frequency, voltage, or current level to another.
- For each power converter, provide a report, manufacturer's data sheet, or other technical data to describe the modulation methods used as well as the mitigation methods use to minimize EMI.

26.7.5 Facility Power

26.7.5.1 General Criteria

The Contractor shall:

- Take power for ATC electronic circuits, HVAC equipment, lighting, elevators and escalators, and other systems from separate branch circuits which are isolated, regulated, backed up, and protected as required. Facility power shall comply with the requirements of the NEC Chapter 2 (Wiring and Protection), Chapter 3 (Wiring Methods and Materials), and Chapter 4 (Equipment for General Use).
- Provide an ATC Power EMC Schedule and drawings detailing the specific design provisions for each equipment item and its power and UPS connections.
- Prepare overall power diagrams that define the power distribution scheme for each system and subsystem and show the ac power with both non-insulated ground and insulated ground circuits serving these systems.

26.7.5.2 High Power

The Contractor shall run high-current power ac cables including phase, ground and neutral conductors, with minimum loop size and conductor separation, physically separated from sensitive circuits, or if near sensitive circuits, twisted or in steel conduit.

26.7.5.3 Utility Power

The Contractor shall:

- Provide a power distribution design which controls potential effects of EMI generated by high power equipment on sensitive electronic equipment. Use separate transformers and distribution buses to ensure high power loads are separated from sensitive loads.
- Use the physical placement of power distribution equipment to increase the immunity of sensitive electronic equipment to EMI generated by high power equipment.
- Route utility power distribution lines to facilities following applicable EMI/EMF regulations and guidelines.

26.7.5.4 Grounding of Uninterruptible Power Supply Circuits

The Contractor shall follow IEEE Std 142-2007, Recommended Practice for Grounding of Industrial and Commercial Power Systems, Section 1.9.1, for UPS grounding arrangements.

26.7.5.5 Remote Powered Locations

Remote ATC locations where utility power is not available may use power supplied from the OCS negative feeder, from a solar storage system, or from another source.

Power at a remote location fed from the negative feeder shall be via a transformer, disconnect, and suitable filtering and power conditioning to protect connected equipment from the transients and harmonics present in the negative feeder.

The selected remote power supply shall make appropriate design provisions for cable, ground, shielding, filtering, and other EMC constraints.

26.7.6 Motors and Controllers

For general-purpose motors and motor controllers used within the ATC system, such as for ventilation equipment, the following criteria shall apply:

- Provide an ATC Motor and Controller EMC Schedule and drawings detailing the specific design provisions for each motor and controller of more than 1 hp.
- Provide each motor starter, controller, or inverter with suitable protection and line and load filtering to minimize transients and surges at start and stop. Provide twisted and/or shielded cables in conduit as appropriate.
- Run input power wires and cables to motors in steel conduit, locate input conductors as far as practical from sensitive equipment, and run wires from the output of the any UPS that powers motors in steel conduit.
- Use soft-start motor controllers or inverters to minimize conducted line transients caused by motor starts. When multiple motors are in a room, coordinate and delay the starting of the motors in a sequence to avoid the intense transient and line dip effects of all motors starting at once.

Service-proven track switch motors and controllers are governed by signal system design practice.

26.7.7 Equipment Rooms and Locations

26.7.7.1 Location

The Contractor shall:

- Within the physical constraints of the planned facilities, locate equipment so that high power sources are physically separated as far as practical from susceptible equipment and cables.
- Where communication equipment, radio, ATC, and similar rooms are near traction power transformers, HVAC motors, or other high current systems, locate the susceptible equipment as far as practical from the stray magnetic fields generated by the transformers, motors, and power cables.
- Preferably, locate high current equipment and cables in rooms that are not adjacent (either vertically or horizontally) to rooms with sensitive and susceptible equipment. Run all input power cables to high current equipment in steel conduit.
- Maximize distance between EMI emitter rooms and EMI susceptible receiver rooms. Lay out the equipment rooms with high current equipment at one end of a suite of rooms and susceptible equipment at the other (far) end of the suite of rooms. To the extent practical, locate rooms so that, for example, starting from the left in a hypothetical plan:
  - Traction power, HVAC, or other high current rooms would be at the leftmost position (room 1)
  - The electrical distribution room (room 2) would be adjacent to and to the right of room 1.
  - The UPS room (room 3) would be adjacent to and to the right of room 2.
  - The ATC room would be adjacent to and to the right of room 3.

26.7.7.2 Equipment Room Shielding

When architectural or structural constraints do not allow room locations and cable and equipment placement per Section 26.7.7.1 and when required by the characteristics of sensitive equipment installed in a room, the Contractor shall use architectural shielding in the sensitive room to mitigate the electric and magnetic fields from the high current equipment. Architectural shielding materials include steel sheet and steel mesh wall linings; other shielding wall linings such as sheet copper, copper mesh, or conductive polyamide mesh; EMI shielded doors, windows, access panels, and air ventilation panels; EMI conductive systems; shielding components; shielding laminates; and EMI shielded equipment racks.

26.7.7.3 ATC Equipment Locations on Rolling Stock

Within the physical constraints of the railcar, the Contractor shall locate equipment so that railcar high power sources and cables are physically separated as far as practical from susceptible ATC equipment and cables.

26.7.8 Equipment Emission and Immunity Limits

26.7.8.1 General

While train control equipment is industrial equipment with similarities to electrical equipment used in other applications, much of it is not COTS equipment. ATC equipment suppliers shall document the achieved level of compliance of their equipment to designated standards.

26.7.8.2 Track Circuit EMC

The ATC and RS suppliers shall jointly establish specific immunity limits to protect ATC equipment, particularly track circuits and track-based data communication circuits, from train-generated interference. These limits shall be implemented by coordinated action by the RS and ATC suppliers during ATC and RS design, implementation, and qualification testing.

For EMC between RS and ATC track circuits, EN 50238-1, Railway applications - Compatibility between RS and train detection Systems, shall govern the relationship. The ATC supplier shall use EN 50238 procedures to document and convert the electromagnetic immunity characteristics of planned wayside equipment into corresponding emission limits which shall apply to RS. The RS supplier shall ensure that the RS emissions comply with the limits developed by the ATC supplier. If necessary, the suppliers shall modify ATC and RS designs to ensure compatibility.

U.S. Department of Transportation Federal Transit Administration test procedures shall govern testing of the compatibility of trains and track circuits. The RS supplier shall perform field qualification tests to demonstrate that the RS conforms to the emission limits using the following procedures:

- UMTA-MA-06-0153-85-6, Conductive Interference in Rapid Transit Signaling Systems Volume II: Suggested Test Procedures
- UMTA-MA-06-0153-85-8, Inductive Interference in Rapid Transit Signaling Systems - Volume II: Suggested Test Procedures

The ATC supplier shall perform field qualification tests to demonstrate that the susceptibility limits of the track circuits are as documented.

Track circuits and related equipment shall be immune to the effects of traction power currents in the OCS, running rails, and ground, and to the effects of utility power transmission and distribution lines which run parallel to or which cross the Authority's right-of-way, whether inside or outside the fence line.

26.7.8.3 ATC Radio EMC

For radio transmission equipment which has been proven in similar service and which has received Type Acceptance per applicable FCC Part 15 regulations, the supplier shall document its suitability, demonstrating that:

- The radio transmission equipment is suited for the planned application.
- The radio transmission equipment has received FCC Part 15 type acceptance.

26.7.8.4 ATC EMC Criteria

Specific ATC system EMC design criteria shall apply for ATC equipment. Euronorm standards govern emissions and immunity for wayside and onboard equipment:

- EN 50121-1, Railway applications - Electromagnetic compatibility. General.
- EN 50121-2, Railway applications - Electromagnetic compatibility. Emissions of the whole railway system to the outside world.
- EN 50121-3-2, Railway applications - Electromagnetic Compatibility. Rolling stock – Apparatus
- EN 50121-4, Railway applications - Electromagnetic Compatibility, Part 4: Emission and immunity of signaling and telecommunications apparatus

Equipment immunity limits for electrostatic discharge, fast transients, and surges shall conform to EN 50121-3-2 and EN 50121-4.

As noted above, track circuit immunity shall be established per EN 50238-1, Railway applications - Compatibility between RS and train detection Systems; EN 50238-2, Railway applications - Compatibility between rolling stock and train detection systems - Part 3: Compatibility with track circuits; and EN 50238-3, Railway applications - Compatibility between rolling stock and train detection systems - Part 3: Compatibility with axle counters.

Each item of electrical or electronic equipment shall be certified and documented to conform to the applicable limits. For equipment that is non-COTS equipment, this documentation shall include a test report, manufacturer's performance data, and acceptance certificates from a qualified test laboratory. Each equipment supplier shall demonstrate and document compliance of each item.

26.7.8.5 ATC Equipment in Equipment Racks

A set of COTS equipment, when installed in a compliant and correct manner in an adequate shielded equipment rack, can be treated as a single item of equipment for the purposes of tests and documentation. However, treatment of a shielded rack of equipment as COTS does not relieve the supplier of responsibility to achieve and document electromagnetic compatibility for the equipment rack and all the equipment in it.

26.7.8.6 ATC Equipment Emissions and Immunity

EN 50121-3-2 governs onboard ATC equipment radiated and conductive emissions and immunity. EN 50121-4 governs wayside ATC equipment radiated and conductive emissions and immunity. Each California High-Speed Train ATC equipment supplier shall provide

equipment which conforms to these limits, as well as test certification or documentation demonstrating compliance.

The ATC equipment immunity limits for electrostatic discharge, fast transients, and surges shall conform to EN 50121-4, Railway applications - Electromagnetic Compatibility, Part 4: Emission and immunity of signaling and telecommunications apparatus.

26.7.9 FCC Type Accepted Radio Equipment for ATC

Radio equipment for ATC shall be FCC Type Accepted. Frequencies for licensed radio equipment shall be coordinated with project needs and as part of the coordination effort with other nearby users.

For FCC Type Accepted radio equipment, provide a Radio EMC Schedule and drawings detailing the specific design provisions for each FCC Type Accepted radio.

26.7.9.1 Radio Equipment Design Considerations

Develop a detailed frequency and intermodulation analysis and report for each radio system, as part of the Radio EMC Schedule. The report shall cover modulation methods and the following:

- **Transmission Lines** – Use transmission lines, with proper terminating impedances, and matched circuits in RF applications.
- **Antenna Placement** – Place antennas to consider radio propagation factors for reliable operation, and also human exposure levels for any antennas which share an environment with patrons, staff, and neighbors.
- **Intermodulation Suppression** – Perform a frequency and interference analysis during the design phase for sites with more than one transmitter and receiver. As appropriate, apply:
  - Cavity filters to attenuate interfering signals from co located transmission equipment.
  - Isolators to further suppress intermodulation.
  - Proper selection of antenna combiners and multi-couplers and segregation of high and low power transmission equipment.

26.7.9.2 ISM Equipment

Industrial, scientific and medical device frequency band (ISM) equipment shall be FCC type-accepted ISM band equipment in either the 2.4 GHz or 5.8 GHz ISM band. ISM design applications shall provide acceptable performance when interference from other ISM band users is present from many other mobile and fixed sources.

26.7.9.3 Radio System Frequency Coordination

The Contractor shall:

- Use frequency coordination to minimize EMI. Frequency coordination shall consist of coordinating the transmission or emission frequencies and the reception or susceptible

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frequencies of all equipment with frequencies already in use in the system and by neighbors.

- Coordinate equipment that transmits or receives on a specific frequency with the list of frequency bands used by other equipment.

26.7.10 Human Exposure to Electromagnetic Fields

The Contractor shall place ATC radio transmit antennas and design the connected radio systems so that human exposure is below the applicable specification limits for EMF in and around the system.

The CPUC EMF Policy in Decision 06-01-042 states:

- Health hazards from exposures to EMF have not been established.
- State and federal public health regulatory agencies have determined that setting numeric exposure limits is not appropriate.
- Existing no-cost and low-cost precautionary-based EMF policy should be continued.

The IEEE developed a set of internationally recognized standards to achieve the safe use of electromagnetic energy in the range of 0 Hz to 300 GHz relative to the potential hazards from exposure of such energy to man, volatile materials, and explosive devices. In compliance with the CPUC decision and international practice, the CHSTP established EMF exposure limits in and around the system per the IEEE standards:

- IEEE Standard C95.6-2002 – IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0-3 kHz [IEEE Std C95.6]
- IEEE Standard C95.1-2005 – IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz [IEEE Std C95.1]

The IEEE standards and these criteria establish MPE limits both for the general population and for authorized people in controlled environments. Only workers, contractors, and other authorized personnel may be in the controlled environments, such as in equipment rooms, or along the Authority's right-of-way near the tracks. The MPE limits recognize that workers and others in these controlled environments have the knowledge to minimize the duration or extent of exposure to the higher levels that may present.

The magnetic field MPE limits for general public and controlled environments shall conform to IEEE Std C95.6 Table 2 and IEEE Std C95.1 Tables 2, 8, and 9. The limit for the general public at 60 Hz is 9.0 G.

The static electric field MPE limits for general public and controlled environments shall conform to the IEEE Std C95.1 Table 4, 8, and 9 and IEEE Std C95.6 Table 4.

The propagating EMF MPE limits for general public and controlled environments shall conform to the IEEE Std C95.1 Table 8 and 9. The MPE limits in the cited revisions of the standards shall apply unless the Contractor establishes that a newer revision of the Standard is applicable and that the newer revision of the Standard provides adequate protection to people near the tracks.

26.8 Traction Electrification System EMC Design Criteria

26.8.1 Equipment and EMC Considerations

The Traction Electrification System (TES) is described in the *Traction Power Supply System* chapter and the *Overhead Contact System and Traction Power Return System* chapter. The TES equipment will consist of the following:

- AC power distribution from two independent high voltage (HV) utility supply circuits to traction power substations
- 2x25kV traction power substations, switching stations, and paralleling stations
- OCS
- Aerial Negative Feeders
- Traction power return system
- Aerial Static/Ground Conductor
- Traction power SCADA, instrumentation, and data network connections
- Equipment includes transformers, cooling equipment, switchgear, overhead contact system hardware, grounding hardware, impedance bonds, cabinets and contents, control panels, monitoring equipment, displays, cables, conduits, ducts, raceways, bus bars, and enclosures.

The 2x25kV configuration reduces propagation of electric and magnetic fields from traction power currents because it minimizes the physical size of the loop in which supply and return currents flow.

Train conducted emissions will include 60 Hz power frequency harmonics with significant levels across the audio frequency band. Train propulsion design criteria developed in coordination with the ATC system supplier shall control the amplitude of higher 60 Hz power frequency harmonics and the susceptibility of ATC equipment to traction power harmonics.

TES equipment EMC provisions shall ensure the following:

- Safe and dependable operation
- No interference with or from neighbors
- Compliance with human exposure limits
  - Magnetic and electric fields

  - Step and touch potentials

Traction power equipment shall conform to electrical safety requirements.

Design and maintenance provisions shall also ensure that EMI cannot compromise the safety level of operations provided by the traction power system.

The following design criteria apply to the traction power system and its interfaces with other systems:

- Cables and cable segregation
- Grounding
- Equipment design
- Facility Power
- Equipment rooms and locations
- Equipment emission and immunity limits
- Requirements for radios
- Human exposure limits
- Effects on adjacent metallic fences and pipelines

The traction power system EMC design criteria are described in following subsections.

26.8.2 Cable

26.8.2.1 General

The Contractor shall select, install, and connect electrical cables with proper shielding, shield grounding, conduit or duct protection, entry protection, routing, and termination to control EMI in copper electrical cables as described in this section. Treat power cables according to required practice for their voltage class.

Electrical cable provisions shall comply with the NEC Chapter 2 (Wiring and Protection), Chapter 3 (Wiring Methods and Materials), Chapter 4 (Equipment for General Use), Chapter 7 (Special Conditions) and Chapter 8 (Communication Systems), except to the extent other Design Criteria provisions specify otherwise.

Electrical cable provisions shall comply with Section VII of CPUC General Order No. 95, 2006.

26.8.2.2 Utility Supply and Overhead Contact System Traction Power Cables

The CPUC EMF Policy in Decision 06-01-042 states:

- Health hazards from exposures to EMF have not been established.

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- State and federal public health regulatory agencies have determined that setting numeric exposure limits is not appropriate.
- Existing no-cost and low-cost precautionary-based EMF policy should be continued.

Utility Supply cables shall conform to the applicable CPUC requirements.

OCS cables (Contact Wire, Messenger Wire, plus aerial Negative Feeders, and Static cables) shall conform to CPUC requirements, if any are put into effect.

Utility Supply and OCS traction power cables shall be laid out to minimize the size and asymmetry of the loop formed between power feeders, the aerial traction power feeder, overhead contact wire, return, aerial and buried ground cables. These cables carry high currents and will generate correspondingly high magnetic field levels.

26.8.2.3 Electrical Cable Categories

For EMC purposes, each cable shall be assigned to one of the cable categories in Table 26-5.

Table 26-5: Electromagnetic Compatibility Cable Categories

ID	Name	Examples, References, Comments
C1	Power at 600 V ac RMS or higher	115 kV feeder.
C2	Traction Power	25 kV ac traction power and return cables.
C3	Power at less than 600 V ac RMS	480 V ac, 120 Vac, Lighting Circuits, HVAC motors, UPS, etc.
C4	NEC Class 1 circuits	NEC Class 1 power limited circuits per NEC 725.41 (A), limited to less than 30 V and 1000 VA. NEC Class 1 remote-control and signaling circuits per NEC 725.21 (B), less than 600 V. Includes safety-critical signaling circuits such as fire alarm.
C5	NEC Class 2 and 3 circuits	Power sources for NEC Class 2 and Class 3 circuits per NEC 725.121, shall be limited per Chapter 9 Table 11(a) and Table 11(b).
C6	Unshielded twisted pair signal circuits	Telephone, speaker level audio output, Ethernet.
C7	Shielded signal circuits including shielded twisted pair, coax, and multi-axial cables	CCTV from camera to converter box, microphone and line level audio input, line level audio output.
C8	Leaky coax cable	Distributed communication antenna.
C9	Optical cable	Backbone network, local area network, CCTV camera feeds from converter box to comm. room.

26.8.2.4 Cable Separation Criteria

Cables in the same cable category may be run together in the same steel conduit, raceway, duct, or cable tray.

Cables in different cable categories shall not be run together in the same cable assembly, conduit, raceway, duct, or cable tray, without engineering justification documenting the specific cables, signals, and protections against EMI for the proposed combination. However, optical cables, C9, may be run together with any other cable.

Cables running parallel to the track shall be segregated in the cable troughs and duct banks according to cable category.

Wires carrying circuits belonging to a single cable category but which use different signal levels shall not be run together in the same cable, without engineering justification documenting the specific cables, signals, and protections against EMI for the proposed combination.

Where cables of dissimilar type, service, or signal level cross, the crossing of the cables and their conduits and raceways shall be perpendicular where practical.

Cable separation design for cables carrying signals shall conform to IEEE Std 1100-2005, Recommended Practice for Powering and Grounding Electronic Equipment, Section 9.9.

26.8.2.5 Cable Shielding

The Contractor shall use shielded cables and steel conduits and ducts to protect components, low voltage circuits, and electronic systems against the effects of undesirable external disturbing EMI sources. A cable shield can:

- Increase immunity and provide additional protection against interference to the enclosed circuits
- Reduce emissions and provide additional reduction of the level of interference emitted by an enclosed circuit.

Wire and cable shielding and shield grounding design for electronic signals shall conform to IEEE Std 1100-2005, Sections 3.3, 4.9, 9.9, 10.2, and 10.4; and to IEEE Std 1143-1994, Guide on Shielding Practice, Section 7.

26.8.2.6 Cable Shield Grounding

The connections of cable shields and the connection of the shields to the grounding system determine the effectiveness of the shielding in mitigating EMI for low-level signals.

The Contractor shall specify and use a coordinated and consistent method for terminating and connecting cable shields to equipment. The method shall conform to these criteria. The Contractor shall document the specific provisions for cable shield grounding at the system and detail level as part of a Cable EMC Schedule. Ensure that the Cable EMC Schedule is fully implemented across all systems.

The general topology for shield connection to power supply ground shall conform to IEEE Std 1100-2005, Sections 8.5, 9.9, 10.2, and 10.4.

Properly terminate cable conductors, shield, and drain wire, if used, on the connector to prevent the inadvertent grounding of the shield or conductor connection via the connector shell to the equipment enclosure or to another unintended potential.

26.8.2.7 Conduit and Duct

The Contractor shall provide metal or non-metallic conduits or ducts for traction power cables, per TES design criteria.

26.8.2.8 Conduit and Duct Bonding and Grounding

Metal conduit and duct can serve as an overall shield for cables carrying sensitive signals, and for cables carrying signals which tend to emit EMI. To provide a shielding function, metal conduit and duct shall be grounded and bonded per the NEC Article 250 where not in conflict with the *Grounding and Bonding Requirements* chapter.

Only hardware listed by a nationally recognized testing laboratory such as UL shall be used to join and bond conduits and ducts to enclosures, including conduit fittings and EMI gaskets.

Fully coordinate IG ac circuit conduit routing and connections with the grounding of the systems powered by insulated ground circuits. Refer to Section 26.8.3.6 for IG details.

26.8.2.9 Entry Protection

The Contractor shall:

- Provide room entry EMI impulse protection for signal wires entering an equipment room.
- Provide enclosure entry EMI impulse protection for signal wires entering an equipment enclosure.

The protection shall consider and be consistent with the cable type, the cable source, and the potential EMI hazards to be protected against. Signal and low voltage power cables entering an equipment room shall be enclosed in steel conduit unless the system designer provides specific technical justification for another entry protection method consistent with the above criteria.

Room entry and line entry impulse protection shall consist of line-to-line and/or line-to-ground protection, as appropriate, for each circuit type. Circuit protections on wires include combinations of lightning arrestors, transient suppressors, fuses, spark gaps, filters, ferrite beads and clamshells, etc.

26.8.2.10 Cable Termination

The Contractor shall terminate all impedance controlled cables, such as coax, with the proper impedance.

26.8.2.11 Circuit Loops

The Contractor shall:

- Minimize the area of circuit loops in which magnetic fields can couple.
- For high current circuits, run the feed and return conductors as closely together as feasible and minimize the length over which the feed and return cables are run separated from one another, to reduce the flux generating loop. To improve the immunity of signal circuits, use twisted pair cables.
- To minimize coupling between the flux generating loop and the signal circuit, maximize the distance between power cables and signal cables, and minimize the distance over which the signal cable runs near and parallel to the power cable.
- Ensure that design layout drawings have sufficient detail to show the physical routing of all conduits and cables, so that EMC compatibility can be designed and documented.

26.8.3 Grounding

26.8.3.1 General

The Contractor shall:

- Make TES equipment grounding provisions so all equipment has a suitable safety ground and so all equipment has suitable EMI-controlling TES ground and return connections.
- Provide a TES Grounding EMC Schedule and drawings detailing the specific design provisions for each equipment item and its grounding connections.
- Prepare an overall grounding diagram that defines the grounding scheme for each system and subsystem, the ac power (both non-insulated ground and insulated ground) circuits serving these systems, and the interconnection means and interconnection points of the grounding systems.

For safety grounding requirements, refer to the *Grounding and Bonding Requirements* chapter.

26.8.3.2 Grounding Categories

For EMC purposes, the Contractor shall use the grounding categories in Table 26-6 to categorize each ground connection. Apply these grounding categories to:

- Minimize the effects of electrical noise generated by the system and by neighboring electrical equipment.
- Minimize disturbing effects within directly affected control equipment and propagating effects on associated equipment which might result from ground currents, fault currents, or nearby lightning strikes.
- Minimize the shock exposure potential which might appear on non-current-carrying equipment or conducting structures, in case an insulation failure energizes the enclosing

structure with a dangerous voltage. Proper grounding of equipment and conducting structures will minimize the shock hazard due to a power line insulation failure.

- Provide a discharge path for stray RF energy.

Table 26-6: Grounding Categories

ID	Name	Examples, References, Comments
G1	Lightning protection ground	The building lightning protection ground shall connect to the power safety ground, at a single point per NFPA 780-2004: Standard for the Installation of Lightning Protection Systems.
G2	Power safety ground	Governed by the NEC Article 250.
G3	Sensitive electronic equipment ground	The sensitive electronic equipment ground should connect by bonding the to the power safety ground only at a single point.
G4	Signal reference structure (SRS) ground	G4 SRS ground configurations include grids and planes which provide a high-frequency common ground reference to which control and communications signals are referenced. A matrix ground mat in or under a sensitive equipment room is a typical SRS implementation. The SRS provides a better reference than a single G3 ground as it provides a lower impedance at high frequencies. If the connection from the G3 sensitive electronic equipment ground to the G2 power safety ground is long, higher impedance in the ground structure results in more electrical noise. A G4 SRS can resolve the problem.
G5	Traction power return	The traction power return and running rails are grounded at each TPF via a connection from the TPF return bus to the TPF ground grid. The running rails are also connected to the aerial ground wire and to the earth at impedance bond locations at intervals along the track.

The Contractor shall:

- Provide a direct, dedicated ground connection when connecting signal and communication ground circuits to a TPF ground grid.
- Identify, coordinate, keep separate, insulate, and appropriately connect the grounds in each of the ground categories in Table 26-6. Where necessary, identify special provisions for grounds in tunnels, trenches, at-grade ballasted or non-ballasted track, and aerial structures or bridges.
- Integrate and coordinate the lightning protection grounding system with the other grounding system designs.

Optical or other galvanic isolation of signals may be needed to create and maintain the separation of grounds.

26.8.3.3 Running Rails

The running rails shall be connected to earth ground via impedance bonds at all TPF locations, including traction power substations, switching stations, and paralleling stations. The running rails shall be also be connected to earth ground via impedance bonds at other wayside locations as necessary to adequately control step and touch potentials.

OCS poles, the static wire, and all other metallic components shall be solidly connected to each other at each location, and the OCS poles shall be grounded through the available path at the OCS pole foundation. However, as noted in the *Grounding and Bonding Requirements* chapter, where an OCS pole can be touched by a person at a passenger station, the OCS pole shall be grounded to the earth but insulated from the static wire.

Coordinate the grounding configuration of the running rails with the requirements of the ATC system since the running rails will be used for ATC circuits and for broken rail protection. Provide platform touch and step voltage protection, including a counterpoise arrangement to control voltage between train and platform.

Refer to the *Grounding and Bonding Requirements* chapter for specific criteria for TES grounding and bonding.

26.8.3.4 Traction Power Return

The rail return system connects the running rails to ground via the TPF transformer or autotransformer neutral bushing. The transformer neutral bushing is connected to the TPF return bus, which is directly connected to the TPF ground grid at each TPF.

Refer to *Traction Power Supply System* chapter for specific criteria.

26.8.3.5 Traction Power Facility Ground and Equipment Safety Ground

Safety ground connection types G1 - G5 in Table 26-6, when connected to a TPF ground grid, shall use a direct, dedicated ground connection.

Specific low-resistance ground resistance criteria may apply to the resistance of the ground grid provided for traction power substations, traction power paralleling stations, and traction power switching stations. Such provisions may be needed to control touch potential along the running rails.

Refer to the *Grounding and Bonding Requirements* chapter for specific criteria for TES grounding and bonding.

26.8.3.6 Industry Standard for Powering and Grounding Electronic Equipment

The designs for powering and grounding TES electronic equipment shall conform to the applicable portions of the National Electric Code, of IEEE Std 1100, and of IEEE Std 142, as adapted for the environment.

For equipment designs and connections, the Contractor shall use the specified techniques for powering and grounding electronic equipment.

Note that in the recommended power and grounding schemes, the "grounded conductor" refers to that leg of the circuit (usually the neutral) that is intentionally held at ground potential. The "grounded conductor" is part of the current-carrying circuit. The "grounding conductor" refers to the conductor(s) that connect(s) exposed metal parts of a device to ground; primarily for safety, secondarily for performance. The "grounding conductor" is not part of the current-carrying circuit.

26.8.3.7 Electronic Equipment Grounding Design Criteria

The Contractor shall:

- Use a safety grounding technique for electronic equipment in racks per IEEE Std 1100-2005, Sections 3.3, 4.9, 8.5, 9.9, 10.2, and 10.4.
- Use a high frequency or RF grounding technique for high frequency signals per IEEE Std 1100-2005, Sections 3.3, 4.6, 8.5, 9.9, 10.2, and 10.4.

The grounding system shall provide that when electronic equipment has a conducting connection to other devices within a structure that all interconnected devices be referenced at the same lightning protection ground (G1) to minimize possible lightning damage. This grounding provision does not apply to power cables.

26.8.3.8 Insulated Ground Design Criteria

Sensitive TES equipment may use an NEC-compliant isolated ground to provide basic fault/personnel protection and to protect the equipment. These criteria refer to the NEC-compliant isolated ground using the IEEE Std 1100 nomenclature, which is “insulated ground” (IG).

For IG connections for equipment in racks, modify the safety grounding configuration from that shown in IEEE Std 1100-2005, Figures 8-17 and 8-18, by placing a listed nonmetallic raceway fitting between the equipment rack and the conduit system, as shown in NEC Handbook Exhibit 250.45. The configuration shall ensure that equipment and enclosures served by an IG power circuit are:

- Correctly and safety grounded at the IG location.
- Not inadvertently bonded to unintended non-insulated grounding paths.

26.8.4 Equipment Design

26.8.4.1 General

Equipment and system designs shall control emissions and increase EMI immunity. Design considerations include placement, enclosures, filters, interconnect design, component characteristics, and modulation methods.

The Contractor shall:

- Specify and implement design provisions for equipment placement, enclosures, filters, interconnect design, component characteristics, and modulation methods, for each equipment item, per the following subsections.
- Ensure that plan and elevation drawings show sufficient detail of the layout of equipment in each rack, the layout of racks within a room, and ancillary equipment within a room, so that EMC compatibility can be designed and documented.

26.8.4.2 Placement

The Contractor shall place high power potential sources as far as practical from sensitive potential susceptible equipment, to minimize magnetic and electric field coupling between nearby pieces of equipment.

26.8.4.3 Enclosures

The Contractor shall:

- Install TES electronic equipment in a suitable EMI-Shielded Equipment Rack Cabinet.
- Protect signal and power lines entering enclosures from EMI by using appropriate cable termination techniques as well as proper conduit fittings, gaskets, etc.
- Enclose cables entering or leaving electronic enclosures in steel conduit, unless otherwise specifically justified by engineering documentation.
- A double wall shielded equipment enclosure may be necessary for sensitive equipment located near a powerful emissions source. In such cases, the inner enclosure shall be connected to the signal reference structure ground or IG, while the outer enclosure shall be connected to the power safety ground.
- Use shielded enclosures, metal ducts, and metal conduits to control the electromagnetic coupling between and from equipment and wiring.

Within enclosures, the Contractor shall:

- Carefully bundle, twist, shield, protect, route, and properly terminate high current cables such as motor cables, to minimize uncontrolled emissions. Ensure that the cable installation does not exceed the minimum bend radius for the cable.
- Connect low voltage cable shields to the appropriate low voltage ground at the source and, per IEEE Std 1100-2005, Sections 3.3 and 8.5 and IEEE Std 1143-1994, Section 7, to the receiver-end equipment.
- Use twisted pair and shielded cables, coax, or multiax for sensitive signals.
- Place inductive components perpendicularly to nearby susceptible components to minimize the exposure to stray flux.

26.8.4.4 Filters

The Contractor shall:

- Use appropriate low-pass filters on wired connections. Filters minimize conducted emissions from a piece of equipment into other pieces of equipment and improve the immunity of the equipment to conducted emissions on the connecting wires.
- Provide filters on power inputs and outputs to and from ac inverters and converters, transmitters, receivers, and signal circuits.
- Use supply suitable transient suppressors for relay contacts switching inductive loads, including relay and contactor coils.

26.8.4.5 Interconnect Design

The Contractor shall use appropriate techniques to minimize emission and maximize immunity of power and signal conductors, including:

- Arrange wires, cables, and conduits to physically separate signals with different signal type, voltage and energy levels
- Separate and shield circuits carrying power, high level signals, and low level signals
- Use balanced circuits with coordinated current return paths
- Minimize the loop area between source and return conductors
- Use photocouplers or optical fiber to galvanically isolate circuit potentials when needed.
- Shield all sensitive signal conductors in suitable electric and magnetic shielding structures using appropriate combinations of steel conduit and shielded cable.
- Connect shields to appropriate system ground at the high energy end.

The Contractor shall:

- Use matching networks to match transmission line and antenna systems to maximize performance and minimize loss and reduce EMI for controlled impedance circuits such as radio frequency signals.
- Use shielded cables that have shield coverage of at least 90 percent
- Use guard shields to improve immunity as required for sensitive electronic circuits.
- Use optical cables, optically-isolated signals, or other galvanic isolation for connection between equipment enclosures, whenever practical.
- Use isolation transformers, chokes and/or isolators for sensitive audio, video, and data circuits as required.

26.8.4.6 Component Characteristics

The Contractor shall select appropriate components to reduce EMI. These include:

- For power converters, such as UPS, dc-to-ac inverters, and variable speed motor drives, use inductor-capacitor line EMI filters on each power input and output, to reduce power frequency and switching harmonic currents and radiated emissions.
- Ferrite beads and clamshells reduce emissions from signal cables and mitigate line-to-ground (common mode) and line-to-line (differential mode) noise.
- Use LCD displays for computers. Do not use CRT displays.

26.8.4.7 Modulation Methods

The Contractor shall:

- Use a modulation method which controls and minimizes the conducted, inductive, and radiated emissions of the equipment for all equipment which converts power from one frequency, voltage, or current level to another.
- For each power converter, provide a report, manufacturer's data sheet, or other technical data to describe the modulation methods used as well as the mitigation methods use to minimize EMI.

26.8.5 Facility Power

26.8.5.1 General Criteria

The Contractor shall:

- Take power for TES electronic circuits, HVAC equipment, lighting, elevators and escalators, and other systems from separate branch circuits which are isolated, regulated, backed up, and protected as required. Facility power shall comply with the requirements of the NEC Chapter 2 (Wiring and Protection), Chapter 3 (Wiring Methods and Materials), and Chapter 4 (Equipment for General Use).
- Provide a TES Power EMC Schedule and drawings detailing the specific design provisions for each equipment item and its power and UPS connections.
- Prepare overall power diagrams that define the power distribution scheme for each system and subsystem and show the ac power with both non-insulated ground and insulated ground circuits serving these systems.

26.8.5.2 High Power

The Contractor shall run high-current power ac cables including phase, ground and neutral conductors, with minimum loop size and conductor separation. Physically separate sensitive circuits from high power cables.

26.8.5.3 Utility Power

Utility power distribution lines shall be routed and carried to facilities following applicable EMI/EMF regulations and guidelines:

- CPUC General Order 95, Overhead Electric Line Construction
- Southern California Edison, EMF Design Guidelines For Electrical Facilities.
- Pacific Gas & Electric Company, Transmission Line EMF Design Guidelines.

CPUC decisions 93-11-013 and 06-01-042 require investor owned electric utility companies to implement no-cost and low-cost steps to reduce EMF levels. These include:

- Increasing the distance from the lines to occupied facilities:
  - Increasing pole (structure) height,
  - Increasing the width of right-of-way, and/or
  - Locating power lines closer to the centerline of the corridor.
- Reducing conductor (phase) spacing.
- Optimizing phasing in a multi-circuit corridor.
- Converting single-phase to split-phase circuits.
- Placing facilities underground.
- Reducing line current by:
- Reducing load
- Improving power factor
- For a given load, providing power at a higher voltage.

CPUC decision 06-01-042 defines “low cost” mitigation of EMF levels to be approximately 4 percent of total project costs, and prioritizes the allocation of mitigation costs according to land use types, as follows:

- Schools and licensed day care
- Residential
- Commercial/industrial
- Recreational
- Agricultural
- Undeveloped land

Construction, relocation, or upgrading of a transmission line requires the utility to make a filing under CPUC GO 131, Rules Relating to the Planning and Construction of Electric Generation, Transmission/Power/Distribution Line Facilities and Substations Located in California.

The California Department of Education established setback limits for locating a school site property line near the edge of easements for any electrical power lines rated 50 kV and above:

- 100 ft for 50 to 133 kV power lines
- 150 ft for 220 to 230 kV power lines
- 350 ft for 500 to 550 kV power lines

Note that the 25 kV OCS lines are not covered by this criterion; however, utility distribution lines to TES power stations are likely to be covered by this criterion.

26.8.5.4 Grounding of Uninterruptible Power Supply Circuits

The Contractor shall follow IEEE Std 142-2007, Recommended Practice for Grounding of Industrial and Commercial Power Systems, Section 1.9.1, for UPS grounding arrangements.

26.8.5.5 Remote Powered Locations

Remote locations where utility power is not available may use power supplied from the OCS negative feeder, from a solar storage system, or from another source.

Power at a remote location fed from the negative feeder shall be via a transformer, disconnect, and suitable filtering and power conditioning to protect connected equipment from the transients and harmonics present in the negative feeder.

The selected remote power supply shall make appropriate design provisions for cable, ground, shielding, filtering, and other EMC constraints.

26.8.6 Motors and Controllers

If motors and motor controllers are used within the TES, such as for ventilation equipment, the following criteria shall apply:

- Provide a TES Motor and Controller EMC Schedule and drawings detailing the specific design provisions for each motor and controller of more than 1 hp.
- Provide each motor starter, controller, or inverter with suitable protection and line and load filtering to minimize transients and surges at start and stop. Provide twisted and/or shielded cables in conduit as appropriate.
- Run input power wires and cables to motors in steel conduit, locate input conductors as far as practical from sensitive equipment, and run wires from the output of the any UPS that powers motors in steel conduit.
- Use soft-start motor controllers or inverters to minimize conducted line transients caused by motor starts. When multiple motors are in a room, coordinate and delay the starting of the motors in a sequence to avoid the intense transient and line dip effects of all motors starting at once.

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26.8.7 Equipment Rooms and Locations

26.8.7.1 Location

The Contractor shall:

- Within the physical constraints of the planned facilities, locate equipment so that high power sources are physically separated as far as practical from susceptible equipment and cables.
- Where communication equipment, radio, ATC, and similar rooms are near traction power transformers, HVAC motors, or other high current systems, locate the susceptible equipment as far as practical from the stray magnetic fields generated by the transformers, motors, and power cables.
- Preferably, locate high current equipment and cables in rooms that are not adjacent (either vertically or horizontally) to rooms with sensitive and susceptible equipment. Run high current input power cables, other than traction power cables, in steel conduit.
- Maximize distance between EMI emitter rooms and EMI susceptible receiver rooms. Lay out the equipment rooms with high current equipment at one end of a suite of rooms and susceptible equipment at the other (far) end of the suite of rooms. To the extent practical, locate rooms so that, for example, starting from the left in a hypothetical plan:
  - Traction power, HVAC, or other high current rooms would be at the leftmost position (room 1)
  - The electrical distribution room (room 2) would be adjacent to and to the right of room 1.
  - The UPS room (room 3) would be adjacent to and to the right of room 2.
  - The communications rooms would be adjacent to and to the right of room 3.

26.8.7.2 Equipment Room Shielding

When architectural or structural constraints do not allow room locations and cable and equipment placement per Section 26.8.7.1 and when required by the characteristics of sensitive equipment installed in a room, the Contractor shall use architectural shielding in the sensitive room to mitigate the electric and magnetic fields from the high current equipment. Architectural shielding materials include steel sheet and steel mesh wall linings; other shielding wall linings such as sheet copper, copper mesh, or conductive polyamide mesh; EMI shielded doors, windows, access panels, and air ventilation panels; EMI conductive systems; shielding components; shielding laminates; and EMI shielded equipment racks.

26.8.8 Equipment Emission and Immunity Limits

26.8.8.1 General

While traction power equipment is industrial equipment with similarities to electrical equipment broadly used in other applications, it is non-COTS equipment. TES equipment suppliers shall document the achieved level of compliance of their equipment to designated standards.

Other specific criteria below also apply.

26.8.8.2 Telephone Interference Criteria

Harmonic currents or voltages generated by the traction power system can affect the performance of communication and other systems. These effects can be minimized by the placement of feeder, return, and ground conductors on the overhead and track structures, by controlling the phase angle of train power converters to minimize harmonics, and by the appropriate use of onboard filters. Telephone interference criteria limits are provided in IEEE Std 519, Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems, Section 11.6. Rolling stock emissions into the traction power system shall conform to the IEEE Std 519 Section 11.6 limits.

26.8.8.3 Traction Power EMC Design and Emission Standards

Traction power equipment shall conform to the following EMC emissions and immunity specifications:

- EN 50121-1, Railway applications - Electromagnetic compatibility. General.
- EN 50121-2, Railway applications - Electromagnetic compatibility. Emissions of the whole railway system to the outside world.
- EN 50121-5, Railway applications - Electromagnetic compatibility. Emission and immunity of fixed power supply installations and apparatus.
- EN 61000-6-4, Electromagnetic Compatibility (EMC) – Part 6-4: Generic Standards – Emission standard for industrial environments

IEEE Standards specify design, safety, and EMC aspects of traction power system equipment:

- Standard 80, Guide for Safety in AC Substation Grounding
- Standard 519, Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems
- Standard 525, Guide for the Design and Installation of Cable Systems in Substations.

Since traction power equipment is non-COTS equipment, the suppliers shall certify that their equipment conforms to the limits and standards specified in the following sections.

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EN 50121-2 governs radiated emissions of the system into the environment during train operation.

For the radiated magnetic field and electric field emission limits for the system including Rolling Stock, track, and OCS during train operation, the "A" curve applies.

EN 50121-2 shows radiated magnetic and electric field emission limits for substations.

EN 50121-5 governs TES fixed power supply equipment radiated and conductive emissions and immunity. EN 50121-2 limits in the previous section apply to higher voltage equipment. Each TES equipment supplier shall provide equipment which conforms to these limits, as well as test certification or documentation demonstrating compliance.

The non-COTS TES equipment immunity limits for electrostatic discharge, fast transients, and surges shall conform to EN 50121-5, Railway applications - Electromagnetic Compatibility, Part 5: Emission and immunity of fixed power supply installations and apparatus.

26.8.8.4 Compatibility with Adjacent Airports and Avionic Equipment

The Contractor shall assess whether radiated electric field emissions from the TES or RS could interfere with aviation equipment or operations at commercial and general airports adjacent to the alignment. The assessment shall consider the ambient electromagnetic environment, radiated emissions and other electromagnetic characteristics of the TES, OCS, and RS, as well as potentially sensitive aviation equipment.

26.8.9 FCC Type Accepted Radio Equipment

Radio equipment, if any, shall be FCC Type Accepted. Refer to Section 26.6.9.

26.8.10 Human Exposure to Electromagnetic Fields

The Contractor shall design the TES and OCS so that human exposure is below the applicable specification limits for EMF in and around the system.

The CPUC EMF Policy in Decision 06-01-042 states:

- Health hazards from exposures to EMF have not been established.
- State and federal public health regulatory agencies have determined that setting numeric exposure limits is not appropriate.
- Existing no-cost and low-cost precautionary-based EMF policy should be continued.

The IEEE developed a set of internationally recognized standards to achieve the safe use of electromagnetic energy in the range of 0 Hz to 300 GHz relative to the potential hazards from exposure of such energy to man, volatile materials, and explosive devices. In compliance with the CPUC decision and international practice, the CHSTP established EMF exposure limits in and around the system per the IEEE standards:

- IEEE Standard C95.6-2002 - IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0-3 kHz [IEEE Std C95.6]
- IEEE Standard C95.1-2005 - IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz [IEEE Std C95.1]

The IEEE standards and these criteria establish MPE limits both for the general population and for authorized people in controlled environments. Only workers, contractors, and other authorized personnel may be in the controlled environments, such as in equipment rooms, or along the right of way near the tracks. The MPE limits recognize that workers and others in these controlled environments have the knowledge to minimize the duration or extent of exposure to the higher levels that may present.

26.8.10.1 Maximum Permissible Exposure Limits

The magnetic field MPE limits for general public and controlled environments shall conform to IEEE Std C95.6 Table 2 and IEEE Std C95.1 Tables 2, 8, and 9. At 60 Hz (the frequency of the traction power system), the IEEE Std 95.6 Table 2 provides a MPE limit of 9.0 G for the general public. This applies in all areas open to the public near and around TES equipment including the OCS.

The IEEE Standard C95.6 MPE for controlled environments in which employees work is 27.1 G. This limit applies to areas not open to the public, such as inside TPFs.

Implanted medical device manufacturers and U.S. research laboratories have established exposure limits for people with implanted medical devices such as pacemakers. The recommended limit is 1.0 G for frequencies up to 10 kHz, including the traction power frequency of 60 Hz. EMF levels above the recommended 1.0G limit may exist inside traction power facilities. TPF sites will be normally unmanned; workers will enter only periodically, for example, to perform routine maintenance. The safety program will disclose health risks to employees who have implanted medical devices and will preclude workers with implanted medical devices from entering any TPF with levels above the recommended limits.

The static electric field MPE limits for general public and controlled environments shall conform to the IEEE Std C95.1 Table 4, 8, and 9 and IEEE Std C95.6 Table 4.

The propagating EMF MPE limits for general public and controlled environments shall conform to the IEEE Std C95.1 Table 8 and 9. The MPE limits in the cited revisions of the standards shall apply unless the Contractor establishes that a newer revision of the Standard is applicable and that the newer revision of the Standard provides adequate protection to people near the tracks.

26.8.11 Effects on Parallel Adjacent Metal Structures

If the ROW runs parallel to ungrounded or partially grounded metal irrigation systems, metal fences, pipelines, or other metal structures for significant distances, a neighbor could experience a nuisance shock when touching the metal structure and a grounded metal object.

The system shall include normal project design features to preclude nuisance shocks, which can consist of either fully grounding the metal structure, fully insulating the metal structure, or segmenting the structure so that the conductive path parallel to the track is interrupted. The project shall protect metal structures within a to-be-determined specified lateral distance from the alignment.

Fences with metal fence posts, buried metal pipelines, and movable irrigation pipes on metal wheels are examples of structures which are already adequately grounded. A metal wire fence with wood fence posts is an example of a structure which may not be adequately grounded. A movable irrigation pipe on rubber wheels is an example of a structure which is probably adequately isolated from ground.

26.9 Rolling Stock EMC Design Criteria

26.9.1 Equipment and EMC Considerations

RS equipment will consist of:

- Electrically powered passenger trains, with steel wheels on steel rails, operating at speeds up to 220 mph on a fully grade-separated alignment. Trains will consist of one or two trainsets of electric multiple units (EMUs).
- Passenger train electrical systems, including propulsion; ATC; onboard communications; radio, commercial radio and cell phone; Wifi and other unlicensed radio; passenger entertainment and communications; trainline network and data systems; HVAC, auxiliary electric, and lighting equipment; and doors.
- Work trains and cars.

The performance requirements of rolling stock equipment shall be as described in the CHSTP Rolling Stock specification.

RS equipment EMC provisions shall ensure:

- Safe and dependable operation
- No interference:
  - Within the train and with passenger equipment on the train
  - With the ATC system
  - With or from radio communications
  - With or from neighbors
- Compliance with human exposure limits:
  - Magnetic and electric fields

- – Step and touch potentials

RS equipment shall conform to electrical safety requirements. Design and maintenance provisions shall also ensure that EMI cannot compromise the safety level of operations achieved by the train system.

Rolling stock equipment shall be HSR proven. Train equipment suppliers shall document the achieved level of compliance of their equipment to designated standards.

The following design criteria apply to RS equipment and their interfaces with other systems:

- Cables and cable segregation
- Grounding
- Equipment design
- Motors and controllers
- Equipment cabinets, control spaces and locations
- Equipment emission and immunity limits
- Requirements for radios
- Human exposure limits.

The RS equipment EMC design criteria are described in following subsections.

26.9.2 Cable

26.9.2.1 General

The Contractor shall:

- Use optical interconnection cables wherever it is technically feasible and cost-effective. Optical connections between equipment and equipment locations are immune to EMI.
- Select, install, and connect electrical cables with proper shielding, shield grounding, conduit or duct protection, entry protection, routing, and termination to control EMI in copper electrical cables as described in this section.

Electrical cable provisions shall comply with the NEC Chapter 2 (Wiring and Protection), Chapter 3 (Wiring Methods and Materials), Chapter 4 (Equipment for General Use), Chapter 7 (Special Conditions) and Chapter 8 (*Communication Systems*), except to the extent other Design Criteria provisions specify otherwise.

26.9.2.2 Electrical Cable Categories

For EMC purposes, each cable shall be assigned to one of the cable categories in Table 26-7.

Table 26-7: Electromagnetic Compatibility Cable Categories

ID	Name	Examples, References, Comments
C1	Power at 600 V ac RMS or higher	If used.
C2	Traction Power	25 kV ac traction power and return cables.
C3	Power at less than 600 V ac RMS	480 V ac, 120 V ac, Lighting Circuits, HVAC motors, UPS, etc.
C4	NEC Class 1 circuits	NEC Class 1 power limited circuits per NEC 725.41 (A), limited to less than 30 V and 1000 VA. NEC Class 1 remote-control and signaling circuits per NEC 725.21 (B), less than 600 V. Includes safety-critical signaling circuits such as fire alarm. Not used in RS.
C5	NEC Class 2 and 3 circuits	Power sources for NEC Class 2 and Class 3 circuits per NEC 725.121, shall be limited per Chapter 9 Table 11(a) and Table 11(b). Not used in RS.
C6	Unshielded twisted pair signal circuits	Telephone, speaker level audio output, Ethernet.
C7	Shielded signal circuits including shielded twisted pair, coax, and multi-axial cables	CCTV from camera to converter box, microphone and line level audio input, line level audio output.
C8	Leaky coax cable	Distributed communication antenna.
C9	Optical cable	Onboard fiber optic communication

26.9.2.3 Cable Separation Criteria

Cables in the same cable category may be run together in the same steel conduit, raceway, duct, or cable tray.

Cables in different cable categories shall not be run together in the same cable assembly, conduit, raceway, duct, or cable tray, without engineering justification documenting the specific cables, signals, and protections against EMI for the proposed combination. However, optical cables, C9, may be run together with any other cable.

Wires carrying circuits belonging to a single cable category but which use different signal levels shall not be run together in the same cable, without engineering justification documenting the specific cables, signals, and protections against EMI for the proposed combination.

Where cables of dissimilar type, service, or signal level cross, the crossing of the cables and their conduits and raceways shall be perpendicular where practical.

Cable separation design shall conform to IEEE Std 1100-2005, Recommended Practice for Powering and Grounding Electronic Equipment, Section 9.9.

26.9.2.4 Cable Shielding

The Contractor shall use shielded cables and rigid metal conduits and ducts to protect components, circuits, and systems against the effects of undesirable external disturbing EMI sources. A cable shield can:

- Increase immunity and provide additional protection against interference to the enclosed circuits
- Reduce emissions and provide additional reduction of the level of interference emitted by an enclosed circuit.

Wire and cable shielding and shield grounding design for electronic signals shall conform to IEEE Std 1100-2005, Sections 3.3, 4.9, 9.9, 10.2, and 10.4; and to IEEE Std 142-2007, Guide on Shielding Practice, Section 7.

26.9.2.5 Cable Shield Grounding

The connections of cable shields and the connection of the shields to the grounding system determine the effectiveness of the shielding in mitigating EMI.

The Contractor shall specify and use a coordinated and consistent method for terminating and connecting cable shields to equipment. The method shall conform to these criteria. Document the specific provisions for cable shield grounding at the system and detail level as part of a Cable EMC Schedule. Ensure that the Cable EMC Schedule is fully implemented across all systems.

The general topology for shield connection to power supply ground shall conform to IEEE Std 1100-2005, Sections 8.5, 9.9, 10.2, and 10.4.

The Contractor shall properly terminate cable conductors, shield, and drain wire, if used, on the connector to prevent the inadvertent grounding of the shield or conductor connection via the connector shell to the equipment enclosure or to another unintended potential.

26.9.2.6 Conduit and Duct

Metal conduits or ducts for cables provide mechanical protection and electrical safety as well as additional electromagnetic isolation compared to physical separation of cables. Metal conduits and ducts increase the immunity of and decrease the emissions from enclosed circuits.

The Contractor shall:

- Use rigid galvanized steel or rigid aluminum alloy steel conduit and ducts.
- Run cables in conduit or rigid metal duct on any run that is outside of a single enclosure for any part of its route, except for cables for which engineering justification documents the basis for the cables to be run out of conduit.

26.9.2.7 Conduit and Duct Bonding and Grounding

Metal conduit and duct can serve as an overall shield for cables carrying sensitive signals, and for cables carrying signals which tend to emit EMI. To provide a shielding function, conduit and duct shall be grounded and bonded per the NEC Article 250.

Only hardware listed by a nationally recognized testing laboratory such as UL shall be used to join and bond conduits and ducts to enclosures, including conduit fittings and EMI gaskets.

Fully coordinate IG ac circuit conduit routing and connections with the grounding of the systems powered by insulated ground circuits. Refer to Section 26.9.3.6 for IG details.

26.9.2.8 Entry Protection

The Contractor shall provide enclosure entry EMI impulse protection for wires entering an equipment enclosure.

The protection shall consider and be consistent with the cable type, the cable source, and the potential EMI hazards to be protected against. As noted above, cables entering an equipment room shall be enclosed in rigid metal conduit unless the system designer provides specific technical justification for another entry protection method consistent with the above criteria.

Line entry impulse protection shall consist of line-to-line and/or line-to-ground protection, as appropriate, for each circuit type. Circuit protections on wires include combinations of lightning arrestors, transient suppressors, fuses, spark gaps, filters, ferrite beads and clamshells, etc.

26.9.2.9 Cable Termination

The Contractor shall terminate all impedance controlled cables, such as coax, with the proper impedance.

26.9.2.10 Circuit Loops

The Contractor shall:

- Minimize area of circuit loops in which magnetic fields can couple.
- For high current circuits, run the feed and return conductors as close together as feasible and minimize the length over which the feed and return cables are run separated from one another, to reduce the flux generating loop. To improve the immunity of signal circuits, use twisted pair cables.
- To minimize coupling between the flux generating loop and the signal circuit, maximize the distance between power cables and signal cables, and minimize the distance over which the signal cable runs near and parallel to the power cable.
- Ensure that design layout drawings have sufficient detail to show the physical routing of all conduits and cables, so that EMC compatibility can be designed and documented.

26.9.3 Grounding

26.9.3.1 General

The Contractor shall:

Make onboard equipment grounding provisions so all equipment has a suitable safety ground and so all onboard equipment has suitable EMI-controlling signal ground and return connections.

- Provide a Grounding EMC Schedule and drawings detailing the specific design provisions for each onboard equipment item and its grounding connections.
- Prepare an overall grounding diagram that defines the grounding scheme for each system and subsystem, the ac power (both non-insulated ground and insulated ground) circuits serving these systems, and the interconnection means and interconnection points of the grounding systems.

26.9.3.2 Grounding Categories

For EMC purposes, the Contractor shall use the grounding categories in Table 26-8 to categorize each ground connection. Apply these grounding categories to:

- Minimize the effects of electrical noise generated by the system’s equipment and neighboring electrical equipment.
- Minimize disturbing effects within directly affected control equipment and propagating effects on associated equipment, which might result from ground currents, fault currents, or nearby lightning strikes.
- Minimize the shock exposure potential which might appear on non-current-carrying equipment or conducting structures in case an insulation failure energizes the enclosing structure with a dangerous voltage. Proper grounding of equipment and conducting structures will minimize the shock hazard due to a power line insulation failure.
- Provide a discharge path for stray RF energy.

Table 26-8: Grounding Categories

ID	Name	Examples, References, Comments
G1	Lightning protection ground	Lightning protection ground for RS is typically the same as G2 Chassis Ground.
G2	Power safety ground/Chassis ground	Chassis Ground shall have separate, normally non-conducting ground buses and ground brush connections to running rails.
G3	Sensitive electronic equipment ground	The sensitive electronic equipment ground should connect by bonding the to the power safety ground only at a single point. The connection of G3 to G2 ground may be by a controlled impedance or low impedance.
G4	SRS ground	A G4 SRS ground is typically not used in RS.
G5	Traction power return	G5 Traction Power Return shall be on ground buses and ground brushes separate from the G2 Chassis Ground.

The Contractor shall:

- Identify, coordinate, keep separate, insulate, and appropriately connect the grounds in each of the ground categories in Table 26-8.
- Integrate and coordinate the lightning protection grounding system with the other grounding system designs.

Optical or other galvanic isolation of signals may be needed to create and maintain the separation of grounds.

The grounds for all low voltage systems, including ground connection types G2 to G5 in Table 26-8, shall be isolated from the railcar chassis. All low voltage system grounds shall be tied to a single low voltage reference point per railcar. The single low voltage reference point shall be connected via a suitable non-zero impedance to the chassis and through separate redundant ground brushes via axles and wheels to the running rails.

The railcar chassis and other safety equipment shall be connected via separate redundant ground brushes via axles and wheels to the running rails.

26.9.3.3 Traction Power Return

The G5 train traction power return shall not be connected to the G2 railcar chassis. The train traction power return shall be connected via separate redundant ground brushes via axles and wheels to the running rails.

As noted in Section 26.8 on Traction Electrification System, the traction power return circuit shall be connected to the TPF ground grid at each TPF. In addition, connections shall be made between the running rails and the Aerial Static/Ground wire via impedance bonds at

appropriate intervals between supply station locations. Refer to *Grounding and Bonding Requirements* chapter.

26.9.3.4 Industry Standard for Powering and Grounding Electronic Equipment

The designs for powering and grounding electronic equipment shall conform to the applicable portions of the National Electric Code, of IEEE Std 1100, and of IEEE Std 142, as adapted for the RS environment.

For equipment designs and connections, the Contractor shall use the specified techniques for powering and grounding electronic equipment.

Note that in the recommended power and grounding schemes, the "grounded conductor" refers to that leg of the circuit (usually the neutral) that is intentionally connected to ground. The "grounded conductor" is part of the current-carrying circuit. The "grounding conductor" refers to the conductor(s) that connect(s) exposed metal parts of a device to ground; primarily for safety, secondarily for performance. The "grounding conductor" is not part of the current-carrying circuit.

26.9.3.5 Grounding Design Criteria

The Contractor shall:

- Use a safety grounding technique for equipment in racks per IEEE Std 1100-2005, Sections 3.3, 4.9, 8.5, 9.9, 10.2, and 10.4.
- Use a high frequency or RF grounding technique signals per IEEE Std 1100-2005, Section 3.3, 4.6, 8.5, 9.9, 10.2, and 10.4.

Chassis grounding shall be through dedicated ground brushes. Traction power return shall be by ground brushes separate from the chassis ground brushes. Normally no current flows through the chassis ground brushes.

26.9.3.6 Insulated Ground Design Criteria

IG connections are not generally used in RS. If used, IG connections shall be NEC-compliant isolated ground using the IEEE Std 1100 criteria.

26.9.4 Equipment Design

26.9.4.1 General

Equipment and system designs shall control emissions and increase EMI immunity. Design considerations include placement, enclosures, filters, interconnect design, component characteristics, and modulation methods.

The Contractor shall:

- Specify and implement design provisions for equipment placement, enclosures, filters, interconnect design, component characteristics, and modulation methods, for each equipment item, per the following subsections.
- Ensure that plan and elevation drawings show sufficient detail of the layout of equipment in each rack and the layout of equipment, boxes, and racks within the cab, passenger compartment, underfloor, or rooftop spaces so that EMC compatibility can be designed and documented.

26.9.4.2 Placement

To the extent practical in the RS limited equipment spaces, the Contractor shall separate high power and high voltage equipment and cables from low voltage equipment and cables, to minimize magnetic and electric field coupling between nearby pieces of equipment.

26.9.4.3 Enclosures

The Contractor shall:

- Install electronic equipment in a suitable EMI-Shielded Equipment Rack Cabinet.
- Protect signal and power lines entering enclosures from EMI by using appropriate cable termination techniques as well as proper conduit fittings, gaskets, etc.
- Enclose cables entering or leaving electronic enclosures in rigid metal conduit, unless otherwise specifically justified by engineering documentation.
- A double wall shielded equipment enclosure may be necessary for sensitive equipment located near a powerful emissions source. In such cases, the inner enclosure shall be connected to the signal reference structure ground or IG, while the outer enclosure shall be connected to the power safety ground.
- Use shielded enclosures, metal ducts, and metal conduits to control the electromagnetic coupling between and from equipment and wiring.

Within enclosures, the Contractor shall:

- Carefully bundle, twist, shield, protect, route, and properly terminate high current cables such as motor cables, to minimize uncontrolled emissions. Ensure that the cable installation does not exceed the minimum bend radius for the cable.
- Connect low voltage cable shields to the appropriate low voltage ground at the source and, per IEEE Std 1100-2005, Sections 3.3 and 8.5 and IEEE Std 1143-1994, Section 7, to the receiver-end equipment.
- Use twisted pair and shielded cables, coax, or multiax for sensitive signals.
- Place inductive components perpendicularly to nearby susceptible components to minimize the exposure to stray flux.

26.9.4.4 Filters

The Contractor shall:

- Use appropriate low-pass filters on wired connections. Filters minimize conducted emissions from a piece of equipment into other pieces of equipment and improve the immunity of the equipment to conducted emissions on the connecting wires.
- Provide filters on power inputs and outputs to and from ac inverters and converters, transmitters, receivers, and signal circuits.
- Use supply suitable transient suppressors for relay contacts switching inductive loads, including relay and contactor coils.

26.9.4.5 Interconnect Design

The Contractor shall use appropriate techniques to minimize emission and maximize immunity of power and signal conductors, including:

- Arrange wires, cables, and conduits to physically separate signals with different signal type, voltage and energy levels
- Separate and shield circuits carrying power, high level signals, and low level signals
- Use balanced circuits with coordinated current return paths
- Minimize the loop area between source and return conductors
- Use photocouplers or optical fiber to galvanically isolate circuit potentials when needed.
- Shield all sensitive signal conductors in suitable electric and magnetic shielding structures using appropriate combinations of rigid metal conduit and shielded cable.
- Connect shields to appropriate system ground at the high energy end.

The Contractor shall:

- Use matching networks to match transmission line and antenna systems to maximize performance and minimize loss and reduce EMI for controlled impedance circuits such as radio frequency signals.
- Use shielded cables that have a shield coverage of at least 90 percent
- Use guard shields to improve immunity as required for sensitive electronic circuits.
- Use optical cables, optically-isolated signals, or other galvanic isolation for connection between equipment enclosures, whenever practical.
- Use isolation transformers, chokes and/or isolators for sensitive audio, video, and data circuits as required.

26.9.4.6 Component Characteristics

The Contractor shall select appropriate components to reduce EMI. These include:

- For power converters, such as UPS, dc-to-ac inverters, and variable speed motor drives, use inductor-capacitor line EMI filters on each power input and output, to reduce power frequency and switching harmonic currents and radiated emissions.
- Ferrite beads and clamshells reduce emissions from signal cables and mitigate line-to-ground (common mode) and line-to-line (differential mode) noise.
- Use LCD displays for computers. Do not use CRT displays.

26.9.4.7 Modulation Methods

The Contractor shall use a modulation method which controls and minimizes the conducted, inductive, and radiated emissions of the equipment for all equipment which converts power from one frequency, voltage, or current level to another.

For each power converter, provide a report, manufacturer's data sheet, or other technical data to describe the modulation methods used as well as the mitigation methods use to minimize EMI.

26.9.5 Facility Power

This section is not applicable to RS equipment.

26.9.6 Motors and Controllers

For RS motors and motor controllers including for propulsion and ventilation, the following criteria shall apply:

- Provide a Motor and Controller EMC Schedule and drawings detailing the specific design provisions for each motor and controller of more than 1 hp.
- Provide each motor starter, controller, or inverter with suitable protection and line and load filtering to minimize transients and surges at start and stop. Provide twisted and/or shielded cables in conduit as appropriate.
- To the extent practical, run input power wires and cables to motors and controllers in rigid metal conduit, or tightly bundle wires, and locate high current conductors as far as practical from sensitive equipment,.
- Additional design criteria apply to the train propulsion system, auxiliary power system, and other power converters, as necessary for the train to conform to the applicable equipment emission and immunity limits.

26.9.7 Equipment Locations

To the extent practical in the RS limited equipment spaces, the Contractor shall separate high power and high voltage equipment and cables from low voltage equipment and cables.

26.9.8 Equipment Emission and Immunity Limits

The following EMC standards shall apply to the RS and equipment:

- EN 50121-1, Railway applications - Electromagnetic compatibility. General.
- EN 50121-2, Railway applications - Electromagnetic compatibility. Emissions of the whole railway system to the outside world.
- EN 50121-3-1, Railway applications - Electromagnetic compatibility, Part 3-1: Rolling stock - Train and complete vehicle. The standard governs total railcar radiated emissions within its intended operating environment.
- EN 50121-3-2, Railway applications - Electromagnetic compatibility, Part 3-2: Rolling stock – Apparatus. The standard governs emissions and susceptibility of railcar equipment.

26.9.8.1 Track Circuit EMC

The ATC and RS suppliers shall jointly establish specific immunity limits to protect ATC equipment, particularly track circuits and track-based data communication circuits, from train-generated interference. These limits shall be implemented by coordinated action by the RS and ATC suppliers during ATC and RS design, implementation, and qualification testing.

For EMC between RS and ATC track circuits, EN 50238, Railway applications - Compatibility between RS and train detection Systems, shall govern the relationship. The ATC supplier shall use EN 50238 procedures to document and convert the electromagnetic immunity characteristics of planned wayside equipment into corresponding emission limits which shall apply to RS. The RS supplier shall ensure that the RS emissions comply with the limits developed by the ATC supplier. If necessary, the suppliers shall modify ATC and RS designs to ensure compatibility.

U.S. Department of Transportation Federal Transit Administration test procedures shall govern testing of the compatibility of trains and track circuits. The RS supplier shall perform field qualification tests to demonstrate that the RS conforms to the emission limits using the following procedures:

- UMTA-MA-06-0153-85-6, Conductive Interference in Rapid Transit Signaling Systems Volume II: Suggested Test Procedures
- UMTA-MA-06-0153-85-8, Inductive Interference in Rapid Transit Signaling Systems - Volume II: Suggested Test Procedures

26.9.8.2 Telephone Interference Criteria

Harmonic currents or voltages generated by the traction power system can affect the performance of communication and other systems. These effects can be minimized by the placement of feeder, return, and ground conductors on the overhead and track structures, by controlling the phase angle of train power converters to minimize harmonics, and by the appropriate use of onboard filters. Telephone interference criteria limits are provided in IEEE

Std 519, Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems, Section 11.6. RS shall conform to the IEEE Std 519 Section 11.6 limits.

26.9.8.3 Railcar Emissions

EN 50121-3-1 governs total railcar radiated emissions into the environment. Figures 3-1 and 3-2 show railcar radiated magnetic field and electric field emission limits, for a stopped and for a slowly moving train.

EN 50121-3-1 Section 5 states that immunity for railcars is achieved by assembling the railcar from equipment which complies with a suitable standard such as EN 50121-3-2.

EN 50121-3-1 Figure 1 shows the radiated emission limits for a stopped train. The black solid line applies to RS.

EN 50121-3-1 Figure 2 shows the radiated emission limits for a slowly moving train. The slow moving test is designed to minimize the effects of the interface between the RS pantograph and the OCS. The "A" curve applies to the RS.

EN 50121-3-2 governs railcar equipment radiated and conductive emissions and immunity. Each RS equipment supplier shall provide equipment which conforms to these limits, as well as test certification or documentation demonstrating compliance.

The RS equipment immunity limits for electrostatic discharge, fast transients, and surges shall conform to EN 50121-3-2, Railway applications - Electromagnetic Compatibility, Part 3-2: Rolling stock – Apparatus.

26.9.8.4 Compatibility With Adjacent Airports and Avionic Equipment

The Contractor shall assess whether radiated electric field emissions from the TES, OCS, or RS could interfere with aviation equipment or operations at commercial and general airports adjacent to the line. The assessment shall consider the ambient electromagnetic environment, radiated emissions and other electromagnetic characteristics of the TES, OCS, and RS, as well as potentially sensitive aviation equipment.

26.9.9 FCC Type Accepted Radio Equipment

Radio equipment shall be FCC Type Accepted.

Frequencies for licensed radio equipment shall be coordinated with the system needs and as part of the coordination work with other nearby users.

For FCC Type Accepted radio equipment, provide a Radio EMC Schedule and drawings detailing the specific design provisions for each FCC Type Accepted radio.

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26.9.9.1 Radio Equipment Design Considerations

The Contractor shall develop a detailed frequency and intermodulation analysis and report for each radio system, as part of the Radio EMC Schedule. The report shall cover modulation methods and the following:

- Transmission Lines – Use transmission lines, with proper terminating impedances, and matched circuits in RF applications.
- Antenna Placement – Place antennas to consider radio propagation factors for reliable operation, and also human exposure levels for any antennas which share an environment with patrons, staff, and neighbors.
- Intermodulation Suppression – Perform a frequency and interference analysis during the design phase for sites with more than one transmitter and receiver. As appropriate, apply:
  - Cavity filters to attenuate interfering signals from co located transmission equipment.
  - Isolators to further suppress intermodulation.
  - Proper selection of antenna combiners and multi-couplers and segregation of high and low power transmission equipment.

26.9.9.2 ISM Equipment

Industrial, scientific and medical device frequency band (ISM) equipment shall be FCC type-accepted ISM band equipment in either the 2.4 GHz or 5.8 GHz ISM band. ISM design applications shall provide acceptable performance when interference from other ISM band users is present from many other mobile and fixed sources.

26.9.9.3 Radio System Frequency Coordination

The Contractor shall:

- Use frequency coordination to minimize EMI in the project. Frequency coordination shall consist of coordinating the transmission or emission frequencies and the reception or susceptible frequencies of all equipment with frequencies already in use in the system and by neighbors.
- Coordinate equipment that transmits or receives on a specific frequency with the list of frequency bands used by other equipment.

26.9.10 Human Exposure to Electromagnetic Fields

The Contractor shall place radio transmit antennas and design the connected radio systems so that human exposure is below the applicable specification limits for EMF.

The CPUC EMF Policy in Decision 06-01-042 states:

- Health hazards from exposures to EMF have not been established.

- State and federal public health regulatory agencies have determined that setting numeric exposure limits is not appropriate.
- Existing no-cost and low-cost precautionary-based EMF policy should be continued.

The IEEE developed a set of internationally recognized standards to achieve the safe use of electromagnetic energy in the range of 0 Hz to 300 GHz relative to the potential hazards from exposure of such energy to man, volatile materials, and explosive devices. In compliance with the CPUC decision and international practice, the CHSTP established EMF exposure limits in and around the system per the IEEE standards:

- IEEE Standard C95.6-2002 - IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0-3 kHz [IEEE Std C95.6]
- IEEE Standard C95.1-2005 - IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz [IEEE Std C95.1]

The IEEE standards and these criteria establish MPE limits both for the general population and for authorized people in controlled environments. Only workers, contractors, and other authorized personnel may be in the controlled environments, such as in equipment rooms, or along the right of way near the tracks. The MPE limits recognize that workers and others in these controlled environments have the knowledge to minimize the duration or extent of exposure to the higher levels that may present.

The magnetic field MPE limits for general public and controlled environments shall conform to IEEE Std C95.6 Table 2 and IEEE Std C95.1 Tables 2, 8, and 9. The limit for the general public at 60 Hz is 9.0 G.

Implanted medical device manufacturers and U.S. research laboratories have established exposure limits for people with implanted medical devices such as pacemakers. The recommended limit is 1.0 G for frequencies up to 10 kHz, including the traction power frequency of 60 Hz.

The project shall determine whether an EMF level above the recommended 1.0G limit can occur inside the rolling stock passenger compartments. During rolling stock design and construction, the Contractor shall perform a detailed design assessment to determine worst case level EMF levels inside the passenger compartment, considering the worst case EMF due to OCS and rail currents and the shielding effect of the railcar body. After construction, the Contractor shall test the rolling stock to determine the actual worst case EMF level inside the passenger compartment. The measurements shall be made following procedures in EN 50500, Measurement procedures of magnetic field levels generated by electronic and electrical apparatus in the railway environment with respect to human exposure.

If the actual worst case EMF level exceeds the established limit, the safety program shall ensure that passengers or employees with implanted medical devices are aware of the potential

exposure to a magnetic field above the established limit by placing suitable warning signs in the passenger compartments or on platforms.

The static electric field MPE limits for general public and controlled environments shall conform to the IEEE Std C95.1 Table 4, 8, and 9 and IEEE Std C95.6 Table 4.

The propagating EMF MPE limits for general public and controlled environments shall conform to the IEEE Std C95.1 Table 8 and 9. The MPE limits in the cited revisions of the standards shall apply unless the Contractor establishes that a newer revision of the Standard is applicable and that the newer revision of the Standard provides adequate protection to people near the tracks.

26.10 Station and Facility Equipment EMC Design Criteria

26.10.1 Equipment and Considerations

Station and facility equipment will consist of:

- Elevators and escalators; HVAC; security equipment; and electrical, lighting, and power equipment
- Communications equipment, and optical, wired, and wireless data networks
- Passenger communications and entertainment equipment including closed circuit television, dynamic message signs and displays, public address systems, intercoms, telephones, wireless networks, and traction power cut stations
- Fare collection
- Vending machines
- Radio
- Equipment includes transformers, inverters, converters, motors and controllers, cabinets and contents, control panels, displays, cables, conduits, ducts, raceways, and enclosures.

The stations and facility equipment shall be designed as described in the applicable Design Criteria section for stations and equipment.

Stations and facilities and their equipment EMC provisions shall ensure:

- Safe and dependable operation
- No interference with or from the ATC system, with or from radio communications, and with or from neighbors
- Compliance with human exposure limits
- Magnetic and electric fields
- Step and touch potentials

- Stations and equipment shall conform to electrical safety requirements.

Design and maintenance provisions shall also ensure that EMI cannot compromise the safety level of operations achieved by other systems.

Station and facility equipment includes general purpose industrial equipment, specialized transportation equipment, and COTS equipment. Station and facility equipment suppliers shall document the achieved level of compliance of their equipment to designated standards.

The following design criteria shall apply to stations and facilities, to their equipment systems, and to their interfaces with other systems:

- Cables and cable segregation
- Grounding
- Equipment design
- Facility Power
- Motors and controllers
- Equipment rooms and locations
- Equipment emission and immunity limits
- Requirements for radios
- Human exposure limits.

The stations and equipment EMC design criteria are described in following subsections.

26.10.2 Cable

26.10.2.1 General

The Contractor shall:

- Use optical interconnection cables wherever it is technically feasible and cost-effective. Optical connections between equipment and equipment locations are immune to EMI.
- Select, install, and connect electrical cables with proper shielding, shield grounding, conduit or duct protection, entry protection, routing, and termination to control EMI in copper electrical cables as described in this section.

Electrical cable provisions shall comply with the NEC Chapter 2 (Wiring and Protection), Chapter 3 (Wiring Methods and Materials), Chapter 4 (Equipment for General Use), Chapter 7 (Special Conditions) and Chapter 8 (Communication Systems), except to the extent other Design Criteria provisions specify otherwise.

26.10.2.2 Electrical Cable Categories

For EMC purposes, each cable shall be assigned to one of the cable categories in Table 26-9.

Table 26-9: Electromagnetic Compatibility Cable Categories

ID	Name	Examples, References, Comments
C1	Power at 600 V ac RMS or higher	115 kV feeder.
C2	Traction Power	25 kV ac traction power and return cables.
C3	Power at less than 600 V ac RMS	480 V ac, 120 V ac, Lighting Circuits, HVAC motors, UPS, etc.
C4	NEC Class 1 circuits	NEC Class 1 power limited circuits per NEC 725.41 (A), limited to less than 30 V and 1000 VA. NEC Class 1 remote-control and signaling circuits per NEC 725.21 (B), less than 600 V. Includes safety-critical signaling circuits such as fire alarm.
C5	NEC Class 2 and 3 circuits	Power sources for NEC Class 2 and Class 3 circuits per NEC 725.121, shall be limited per Chapter 9 Table 11(a) and Table 11(b).
C6	Unshielded twisted pair signal circuits	Telephone, speaker level audio output, Ethernet.
C7	Shielded signal circuits including shielded twisted pair, coax, and multi-axial cables	CCTV from camera to converter box, microphone and line level audio input, line level audio output.
C8	Leaky coax cable	Distributed communication antenna.
C9	Optical cable	Backbone network, local area network, CCTV camera feeds from converter box to comm. room.

26.10.2.3 Cable Separation Criteria

Cables in the same cable category may be run together in the same steel conduit, raceway, duct, or cable tray.

Cables in different cable categories shall not be run together in the same cable assembly, conduit, raceway, duct, or cable tray, without engineering justification documenting the specific cables, signals, and protections against EMI for the proposed combination. However, optical cables, C9, may be run together with any other cable.

Cables running parallel to the track shall be segregated in the cable troughs and duct banks according to cable category.

Wires carrying circuits belonging to a single cable category but which use different signal levels shall not be run together in the same cable, without engineering justification documenting the specific cables, signals, and protections against EMI for the proposed combination.

Where cables of dissimilar type, service, or signal level cross, the crossing of the cables and their conduits and raceways shall be perpendicular where practical.

Cable separation design shall conform to IEEE Std 1100-2005, Recommended Practice for Powering and Grounding Electronic Equipment, Section 9.9.

26.10.2.4 Cable Shielding

The Contractor shall use shielded cables and steel conduits and ducts to protect components, circuits, and systems against the effects of undesirable external disturbing EMI sources. A cable shield can:

- Increase immunity and provide additional protection against interference to the enclosed circuits
- Reduce emissions and provide additional reduction of the level of interference emitted by an enclosed circuit.

Wire and cable shielding and shield grounding design shall conform to IEEE Std 1100-2005, Sections 3.3, 4.9, 9.9, 10.2, and 10.4; and to IEEE Std 1143-1994, Guide on Shielding Practice, Section 7.

26.10.2.5 Cable Shield Grounding

The connections of cable shields and the connection of the shields to the grounding system determine the effectiveness of the shielding in mitigating EMI.

The Contractor shall specify and use a coordinated and consistent method for terminating and connecting cable shields to equipment. The method shall conform to these criteria. Document the specific provisions for cable shield grounding at the system and detail level as part of a Cable EMC Schedule. Ensure that the Cable EMC Schedule is fully implemented across all systems.

The general topology for shield connection to power supply ground shall conform to IEEE Std 1100-2005, Sections 8.5, 9.9, 10.2, and 10.4.

Properly terminate cable conductors, shield, and drain wire, if used, on the connector to prevent the inadvertent grounding of the shield or conductor connection via the connector shell to the equipment enclosure or to another unintended potential.

26.10.2.6 Conduit and Duct

The Contractor shall:

- Run specified cables in trackside ducts.

- Metal conduits or ducts for cables provide mechanical protection and electrical safety as well as additional electromagnetic isolation compared to physical separation of cables. Metal conduits and ducts increase the immunity of and decrease the emissions from enclosed circuits.
- Use steel conduit and ducts; do not use aluminum.
- Run cables in steel conduit or steel duct on any run that is outside of a single enclosure for any part of its route, except for cables in the trackside ducts and cables for which for which engineering justification documents the basis for the cables which are run out of conduit.

26.10.2.7 Conduit and Duct Bonding and Grounding

Metal conduit and duct can serve as an overall shield for cables carrying sensitive signals, and for cables carrying signals which tend to emit EMI. To provide a shielding function, conduit and duct shall be grounded and bonded per the NEC Article 250 where not in conflict with the *Grounding and Bonding Requirements* chapter.

Only hardware listed by a nationally recognized testing laboratory such as UL shall be used to join and bond conduits and ducts to enclosures, including conduit fittings and EMI gaskets.

Fully coordinate IG ac circuit conduit routing and connections with the grounding of the systems powered by insulated ground circuits. Refer to Section 26.10.3.6 for IG details.

26.10.2.8 Entry Protection

The Contractor shall:

- Provide room entry EMI impulse protection for wires entering an equipment room.
- Provide enclosure entry EMI impulse protection for wires entering an equipment enclosure.

The protection shall consider and be consistent with the cable type, the cable source, and the potential EMI hazards to be protected against. As noted above, cables entering an equipment room shall be enclosed in steel conduit unless the system designer provides specific technical justification for another entry protection method consistent with the above criteria.

Room entry and line entry impulse protection shall consist of line-to-line and/or line-to-ground protection, as appropriate, for each circuit type. Circuit protections on wires include combinations of lightning arrestors, transient suppressors, fuses, spark gaps, filters, ferrite beads and clamshells, etc.

26.10.2.9 Cable Termination

The Contractor shall terminate all impedance controlled cables, such as coax, with the proper impedance.

26.10.2.10 Circuit Loops

The Contractor shall:

- Minimize the area of circuit loops in which magnetic fields can couple.
- For high current circuits, run the feed and return conductors as closely together as feasible and minimize the length over which the feed and return cables are run separated from one another, to reduce the flux generating loop. To improve the immunity of signal circuits, use twisted pair cables.
- To minimize coupling between the flux generating loop and the signal circuit, maximize the distance between power cables and signal cables, and minimize the distance over which the signal cable runs near and parallel to the power cable.
- Ensure that design layout drawings have sufficient detail to show the physical routing of all conduits and cables, so that EMC compatibility can be designed and documented.

26.10.3 Grounding

26.10.3.1 General

The Contractor shall:

- Make California High-Speed Train equipment grounding provisions so all equipment has a suitable safety ground and so all equipment has suitable EMI-controlling signal ground and return connections.
- Provide a Grounding EMC Schedule and drawings detailing the specific design provisions for each equipment item and its grounding connections.
- Prepare an overall grounding diagram that defines the grounding scheme for each system and subsystem, the ac power (both non-insulated ground and insulated ground) circuits serving these systems, and the interconnection means and interconnection points of the grounding systems.

For safety grounding requirements, refer to the *Grounding and Bonding Requirements* chapter.

26.10.3.2 Grounding Categories

For EMC purposes, use the grounding categories in Table 26-10 to categorize each ground connection. Apply these grounding categories to:

- Minimize the effects of electrical noise generated by system and neighboring electrical equipment.
- Minimize disturbing effects within directly affected control equipment and propagating effects on associated equipment which might result from ground currents, fault currents, or nearby lightning strikes.
- Minimize the shock exposure potential which might appear on non-current-carrying equipment or conducting structures, in case an insulation failure energizes the enclosing structure with a dangerous voltage. Proper grounding of equipment and grounding structures will minimize the shock hazard due to a power line insulation failure.

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- Provide a discharge path for stray RF energy.

Table 26-10: Grounding Categories

ID	Name	Examples, References, Comments
G1	Lightning protection ground	The building lightning protection ground shall connect to the power safety ground, at a single point per NFPA 780-2004: Standard for the Installation of Lightning Protection Systems.
G2	Power safety ground	Governed by the NEC Article 250.
G3	Sensitive electronic equipment ground	The sensitive electronic equipment ground should connect by bonding the to the power safety ground only at a single point.
G4	SRS ground	G4 SRS ground configurations include grids and planes which provide a high-frequency common ground reference to which control and communications signals are referenced. A matrix ground mat in or under a sensitive equipment room is a typical SRS implementation. It provides a better reference than a single G3 ground as it provides a lower impedance at high frequencies. If the connection from the G3 sensitive electronic equipment ground to the G2 power safety ground is long, higher impedance in the ground structure results in more electrical noise. A G4 SRS can resolve the problem.
G5	Traction power return	The traction power return and running rails are grounded at each TPF via a connection from the TPF return bus to the TPF ground grid. The running rails are also connected to the aerial ground wire and to the earth at impedance bond locations at intervals along the track.

The Contractor shall:

- Provide a direct, dedicated ground connection when connecting signal and communication ground circuits to a TPF ground grid.
- Identify, coordinate, keep separate, insulate, and appropriately connect the grounds in each of the ground categories in Table 26-10. Where necessary, identify special provisions for grounds in tunnels, trenches, at-grade ballasted or non-ballasted track, and aerial structures or bridges.
- Integrate and coordinate the lightning protection grounding system with the other grounding system designs.

Optical or other galvanic isolation of signals may be needed to create and maintain the separation of grounds.

26.10.3.3 Traction Power Return

As noted in the following section on traction power, the traction power return circuit shall be connected to the TPF ground grid at each TPF. In addition, the running rails shall be connected

via impedance bonds to the earth and to the Aerial Ground Wire at intervals between TPF locations, to control step and touch voltage hazards.

For safety grounding requirements, refer to the *Grounding and Bonding Requirements* chapter.

26.10.3.4 Industry Standard for Powering and Grounding Electronic Equipment

The designs for powering and grounding electronic equipment shall conform to the applicable portions of the National Electric Code, of IEEE Std 1100, and of IEEE Std 142, as adapted for the environment.

For equipment designs and connections, use the specified techniques for powering and grounding electronic equipment.

Note that in the recommended power and grounding schemes, the "grounded conductor" refers to that leg of the circuit (usually the neutral) that is intentionally held at ground potential. The "grounded conductor" is part of the current-carrying circuit. The "grounding conductor" refers to the conductor(s) that connect(s) exposed metal parts of a device to ground; primarily for safety, secondarily for performance. The "grounding conductor" is not part of the current-carrying circuit.

26.10.3.5 Grounding Design Criteria

The Contractor shall:

- Use a safety grounding technique for equipment in racks per IEEE Std 1100-2005, Sections 3.3, 4.9, 8.5, 9.9, 10.2, and 10.4.
- Use a high frequency or RF grounding technique signals per IEEE Std 1100-2005, Sections 3.3, 4.6, 8.5, 9.9, 10.2, and 10.4.

The grounding system shall provide that when electronic equipment has a conducting connection to other devices within a structure that all interconnected devices be referenced at the same lightning protection ground (G1) to minimize possible lightning damage.

26.10.3.6 Insulated Ground Design Criteria

Sensitive equipment may use an NEC-compliant isolated ground to provide basic fault/personnel protection and to protect the equipment. These criteria refer to the NEC-compliant isolated ground using the IEEE Std 1100 nomenclature, which is insulated ground (IG).

For IG connections for equipment in racks, modify the safety grounding configuration from that shown in IEEE Std 1100-2005, Figures 8-17 and 8-18, by placing a listed nonmetallic raceway fitting between the equipment rack and the conduit system, as shown in NEC Handbook Exhibit 250.45. The configuration shall ensure that equipment and enclosures served by an IG power circuit are:

- Correctly and safety grounded at the IG location.

- Not inadvertently bonded to unintended non-insulated grounding paths.

26.10.4 Equipment Design

26.10.4.1 General

Equipment and system designs shall control emissions and increase EMI immunity. Design considerations include placement, enclosures, filters, interconnect design, component characteristics, and modulation methods.

The Contractor shall:

- Specify and implement design provisions for equipment placement, enclosures, filters, interconnect design, component characteristics, and modulation methods, for each equipment item, per the following subsections.
- Ensure that plan and elevation drawings show sufficient detail of the layout of equipment in each rack, the layout of racks within a room, and ancillary equipment within a room, so that EMC compatibility can be designed and documented.

26.10.4.2 Placement

The Contractor shall place high power potential sources as far as practical from sensitive potential susceptible equipment, to minimize magnetic and electric field coupling between nearby pieces of equipment.

26.10.4.3 Enclosures

The Contractor shall:

- Install electronic equipment in a suitable EMI-Shielded Equipment Rack Cabinet.
- Protect signal and power lines entering enclosures shall be protected from EMI by using appropriate cable termination techniques as well as proper conduit fittings, gaskets, etc.
- Enclose cables entering or leaving electronic enclosures in steel conduit, unless otherwise specifically justified by engineering documentation..
- A double wall shielded equipment enclosure may be necessary for sensitive equipment located near a powerful emissions source. In such cases, the inner enclosure shall be connected to the signal reference structure ground or IG, while the outer enclosure shall be connected to the power safety ground.
- Use shielded enclosures, metal ducts, and metal conduits to control the electromagnetic coupling between and from equipment and wiring.

Within enclosures, the Contractor shall:

- Carefully bundle, twist, shield, protect, route, and properly terminate high current cables such as motor cables, to minimize uncontrolled emissions. Ensure that the cable installation does not exceed the minimum bend radius for the cable.
- Connect low voltage cable shields to the appropriate low voltage ground at the source and, per IEEE Std 1100-2005, Sections 3.3 and 8.5 and IEEE Std 1143-1994, Section 7, to the receiver-end equipment.
- Use twisted pair and shielded cables, coax, or multiax for sensitive signals.
- Place inductive components perpendicularly to nearby susceptible components to minimize the exposure to stray flux.

26.10.4.4 Filters

The Contractor shall:

- Use appropriate low-pass filters on wired connections. Filters minimize conducted emissions from a piece of equipment into other pieces of equipment and improve the immunity of the equipment to conducted emissions on the connecting wires.
- Provide filters on power inputs and outputs to and from ac inverters and converters, transmitters, receivers, and signal circuits.
- Use supply suitable transient suppressors for relay contacts switching inductive loads, including relay and contactor coils.

26.10.4.5 Interconnect Design

The Contractor shall use appropriate techniques to minimize emission and maximize immunity of power and signal conductors, including:

- Arrange wires, cables, and conduits to physically separate signals with different signal type, voltage and energy levels.
- Separate and shield circuits carrying power, high level signals, and low level signals.
- Use balanced circuits with coordinated current return paths.
- Minimize the loop area between source and return conductors.
- Use photocouplers or optical fiber to galvanically isolate circuit potentials when needed.
- Shield all sensitive signal conductors in suitable electric and magnetic shielding structures using appropriate combinations of steel conduit and shielded cable.
- Connect shields to appropriate system ground at the high energy end.

The Contractor shall:

- Use matching networks to match transmission line and antenna systems to maximize performance and minimize loss and reduce EMI for controlled impedance circuits such as radio frequency signals.
- Use shielded cables that have a shield coverage of at least 90 percent
- Use guard shields to improve immunity as required for sensitive electronic circuits.
- Use optical cables, optically-isolated signals, or other galvanic isolation for connection between equipment enclosures, whenever practical.
- Use isolation transformers, chokes and/or isolators for sensitive audio, video, and data circuits as required.

26.10.4.6 Component Characteristics

The Contractor shall select appropriate components to reduce EMI. These include:

- For power converters, such as UPS, dc-to-ac inverters, and variable speed motor drives, use inductor-capacitor line EMI filters on each power input and output, to reduce power frequency and switching harmonic currents and radiated emissions.
- Ferrite beads and clamshells reduce emissions from signal cables and mitigate line-to-ground (common mode) and line-to-line (differential mode) noise.
- Use LCD displays for computers. Do not use CRT displays.

26.10.4.7 Modulation Methods

The Contractor shall:

- Use a modulation method which controls and minimizes the conducted, inductive, and radiated emissions of the equipment for all equipment which converts power from one frequency, voltage, or current level to another.
- For each power converter, provide a report, manufacturer's data sheet, or other technical data to describe the modulation methods used as well as the mitigation methods use to minimize EMI.

26.10.5 Facility Power

26.10.5.1 General Criteria

The Contractor shall:

- Take power for communication electronic circuits, HVAC equipment, lighting, elevators and escalators, and other systems from separate branch circuits which are isolated, regulated, backed up, and protected as required. Facility power shall comply with the requirements of the NEC Chapter 2 (Wiring and Protection), Chapter 3 (Wiring Methods and Materials), and Chapter 4 (Equipment for General Use).

- Provide a Communications Power EMC Schedule and drawings detailing the specific design provisions for each equipment item and its power and UPS connections.
- Prepare overall power diagrams that define the power distribution scheme for each system and subsystem and show the ac power with both non-insulated ground and insulated ground circuits serving these systems.

26.10.5.2 High Power

The Contractor shall run high-current power ac cables including phase, ground and neutral conductors, with minimum loop size and conductor separation, physically separated from sensitive circuits, or if near sensitive circuits, twisted or in steel conduit.

26.10.5.3 Utility Power

The Contractor shall:

- Provide a power distribution design which controls potential effects of EMI generated by high power equipment on sensitive electronic equipment. Use separate transformers and distribution buses to ensure high power loads are separated from sensitive loads.
- Use the physical placement of power distribution equipment to increase the immunity of sensitive electronic equipment to EMI generated by high power equipment.
- Route utility power distribution lines to facilities following applicable EMI/EMF regulations and guidelines.

26.10.5.4 Grounding of Uninterruptible Power Supply Circuits

The Contractor shall follow IEEE Std 142-2007, Recommended Practice for Grounding of Industrial and Commercial Power Systems, Section 1.9.1, for UPS grounding arrangements.

26.10.5.5 Remote Powered Locations

Remote communication locations where utility power is not available may use power supplied from the OCS negative feeder, from a solar storage system, or from another source.

Power at a remote location fed from the negative feeder shall be via a transformer, disconnect, and suitable filtering and power conditioning to protect connected equipment from the transients and harmonics present in the negative feeder.

The selected remote power supply shall make appropriate design provisions for cable, ground, shielding, filtering, and other EMC constraints.

26.10.6 Motors and Controllers

If motors and motor controllers are used within the stations and facilities, such as for ventilation equipment, the following criteria shall apply:

- Provide a Motor and Controller EMC Schedule and drawings detailing the specific design provisions for each motor and controller of more than 1 hp.

- Provide each motor starter, controller, or inverter with suitable protection and line and load filtering to minimize transients and surges at start and stop. Provide twisted and/or shielded cables in conduit as appropriate.
- Run input power wires and cables to motors in steel conduit, locate input conductors as far as practical from sensitive equipment, and run wires from the output of the any UPS that powers motors in steel conduit.
- Use soft-start motor controllers or inverters to minimize conducted line transients caused by motor starts. When multiple motors are in a room, coordinate and delay the starting of the motors in a sequence to avoid the intense transient and line dip effects of all motors starting at once.

26.10.7 Equipment Rooms and Locations

26.10.7.1 Location

The Contractor shall:

- Within the physical constraints of the planned stations and facilities, locate equipment so that high power sources are physically separated as far as practical from susceptible equipment and cables.
- Where communication equipment, radio, ATC, and similar rooms are near traction power transformers, HVAC motors, or other high current systems, locate the susceptible equipment as far as practical from the stray magnetic fields generated by the transformers, motors, and power cables.
- Preferably, locate high current equipment and cables in rooms that are not adjacent (either vertically or horizontally) to rooms with sensitive and susceptible equipment. Run all input power cables to high current equipment in steel conduit.
- Maximize distance between EMI emitter rooms and EMI susceptible receiver rooms. Lay out the equipment rooms with high current equipment at one end of a suite of rooms and susceptible equipment at the other (far) end of the suite of rooms. To the extent practical, locate rooms so that, for example, starting from the left in a hypothetical plan:
  - Traction power, HVAC, or other high current rooms would be at the leftmost position (room 1).
  - The electrical distribution room (room 2) would be adjacent to and to the right of room 1.
  - The UPS room (room 3) would be adjacent to and to the right of room 2.
  - The communications rooms would be adjacent to and to the right of room 3.

26.10.7.2 Equipment Room Shielding

When architectural or structural constraints do not allow room locations and cable and equipment placement per Section 26.10.7.1 and when required by the characteristics of sensitive equipment installed in a room, the Contractor shall use architectural shielding in the sensitive room to mitigate the electric and magnetic fields from the high current equipment. Architectural shielding materials include steel sheet and steel mesh wall linings; other shielding wall linings such as sheet copper, copper mesh, or conductive polyamide mesh; EMI shielded doors, windows, access panels, and air ventilation panels; EMI conductive systems; shielding components; shielding laminates; and EMI shielded equipment racks.

26.10.8 Equipment Emission and Immunity Limits

Typical rail station and facility equipment makes broad use of COTS equipment. COTS equipment shall meet U.S. FCC regulations and other EMC standards governing emissions and immunity. Manufacturers of COTS equipment shall guarantee their equipment meets required regulations and selected published standards, but they will generally not test to or modify their equipment to meet standards other than the required and selected published ones.

All electrical and electronic equipment shall conform to the following electromagnetic emission and immunity limits and related requirements.

Each item of electrical or electronic equipment shall be certified and documented to conform to the applicable limits. For equipment which is non-COTS equipment, this documentation shall include a test report, manufacturer's performance data, and acceptance certificates from a qualified test laboratory. Each equipment supplier shall demonstrate and document compliance of each item.

26.10.8.1 COTS Station and Facility Equipment Emission Limits

COTS equipment which is not radio transmission equipment shall meet the following conducted and radiated emission requirements of Part 15 of Title 46 of the Code of Federal Regulation (FCC Part 15), sub-part B:

- Section 15.107(b), Conducted Limits, Class A digital devices
- Section 15.109(b), Radiated Limits, Class A digital devices

FCC Part 15.3(h) defines Class A devices as digital devices which are marketed for commercial, industrial, or business use; not for use in general public or home applications.

FCC Part 15 does not provide immunity limits.

COTS non-radio equipment shall be proven in similar service and shall have a Certification or a Declaration of Conformity per FCC Part 15, sub-part B, Class A devices. For such equipment, provide documentation of the suitability or test results. Suitability considerations are:

- The equipment is COTS.

- The equipment is suited for the planned application.
- The equipment has Certification or a Declaration of Conformity per FCC Part 15, sub-part B, Class A device regulations.

A set of COTS equipment, when installed in a compliant and correct manner in an adequate shielded equipment rack, can be treated as a single item of COTS equipment for the purposes of tests and documentation. However, treatment of a shielded rack of equipment as COTS does not relieve the supplier of responsibility to achieve and document electromagnetic compatibility for the equipment rack and all the equipment in it.

26.10.8.2 Non-COTS Station and Facility Equipment Emissions and Immunity

Non-COTS station and facility equipment, if any, shall conform to the radiated and conducted immunity limits of EN 50121-4, Railway applications - Electromagnetic Compatibility, Part 4: Emission and immunity of signaling and telecommunications apparatus.

Per EN 50121-4, the non-COTS communications equipment radiated and conducted emission limits shall conform to EN 61000-6-4, Electromagnetic Compatibility, Part 6-4: Generic Standards - Emission Standard for industrial environments. Each station and facility equipment supplier shall provide equipment which conforms to the applicable limits, as well as test certification or documentation demonstrating compliance.

In addition, FCC Part 15 governs both COTS and non-COTS communications equipment radiated and conducted emissions, other than for vehicle equipment. FCC limits are more restrictive than EN 50121-4 limits.

The non-COTS station and facility equipment immunity limits for electrostatic discharge, fast transients, and surges shall conform to EN 50121-4, Railway applications - Electromagnetic Compatibility, Part 4: Emission and immunity of signaling and telecommunications apparatus.

26.10.9 FCC Type Accepted Radio Equipment for Stations and Facilities

Station and facility radio equipment shall be FCC Type Accepted. Frequencies for licensed radio equipment shall be coordinated with the project needs and as part of the coordination effort with other nearby users.

For FCC Type Accepted radio equipment, the Contractor shall provide a Radio EMC Schedule and drawings detailing the specific design provisions for each FCC Type Accepted radio.

For COTS radio transmission equipment which has been proven in similar service and which has received Type Acceptance per applicable FCC Part 15 regulations, the supplier shall document its suitability, demonstrating that:

- The radio transmission equipment is suited for the planned application.
- The radio transmission equipment has received FCC Part 15 type acceptance.

26.10.9.1 Radio Equipment Design Considerations

The Contractor shall develop a detailed frequency and intermodulation analysis and report for each radio system, as part of the Radio EMC Schedule. The report shall cover modulation methods and the following:

- Transmission Lines – Use transmission lines, with proper terminating impedances, and matched circuits in RF applications.
- Antenna Placement – Place antennas to consider radio propagation factors for reliable operation, and also human exposure levels for any antennas which share an environment with patrons, staff, and neighbors.
- Intermodulation Suppression – Perform a frequency and interference analysis during the design phase for sites with more than one transmitter and receiver. As appropriate, apply:
  - Cavity filters to attenuate interfering signals from co located transmission equipment.
  - Isolators to further suppress intermodulation.
  - Proper selection of antenna combiners and multi-couplers and segregation of high and low power transmission equipment.

26.10.9.2 ISM Equipment

Industrial, scientific and medical device frequency band (ISM) equipment shall be FCC type-accepted ISM band equipment in either the 2.4 GHz or 5.8 GHz ISM band. ISM design applications shall provide acceptable performance when interference from other ISM band users is present from many other mobile and fixed sources.

26.10.9.3 Radio System Frequency Coordination

The Contractor shall:

- Use frequency coordination to minimize EMI. Frequency coordination shall consist of coordinating the transmission or emission frequencies and the reception or susceptible frequencies of all equipment with frequencies already in use in the system and by neighbors.
- Coordinate equipment that transmits or receives on a specific frequency with the list of frequency bands used by other equipment.

26.10.10 Human Exposure to Electromagnetic Fields

The Contractor shall place station and facility radio transmit antennas and design the connected radio systems so that human exposure is below the applicable specification limits for EMF in and around the system area.

The CPUC EMF Policy in Decision 06-01-042 states:

- Health hazards from exposures to EMF have not been established.

- State and federal public health regulatory agencies have determined that setting numeric exposure limits is not appropriate.
- Existing no-cost and low-cost precautionary-based EMF policy should be continued.

The IEEE developed a set of internationally recognized standards to achieve the safe use of electromagnetic energy in the range of 0 Hz to 300 GHz relative to the potential hazards from exposure of such energy to man, volatile materials, and explosive devices. In compliance with the CPUC decision and international practice, the CHSTP established EMF exposure limits in and around the system per the IEEE standards:

- IEEE Standard C95.6-2002 - IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0-3 kHz [IEEE Std C95.6]
- IEEE Standard C95.1-2005 - IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz [IEEE Std C95.1]

The IEEE standards and these criteria establish MPE limits both for the general population and for authorized people in controlled environments. Only workers, contractors, and other authorized personnel may be in the controlled environments, such as in equipment rooms, or along the right of way near the tracks. The MPE limits recognize that workers and others in these controlled environments have the knowledge to minimize the duration or extent of exposure to the higher levels that may present.

26.10.10.1 Maximum Permissible Exposure Limits

Implanted medical device manufacturers and U.S. research laboratories have established exposure limits for people with implanted medical devices such as pacemakers. The recommended limit is 1.0 G for frequencies up to 10 kHz, including the traction power frequency of 60 Hz.

Figures 26-1 and 26-2 show the estimated worst-case 60 Hz magnetic field caused by a high-speed train vs. perpendicular distance from the center of the ROW. For this calculation, the train is assumed to continuously draw 930 A at 60 Hz. Figure 26-1 shows the peak magnetic field level at a location close to the traction power substation vs. lateral distance from the ROW centerline track. The peak in the graph is at the centerline of the track containing the train. Figure 26-2 shows the peak magnetic field level at greater lateral distances from the track, on a log-log scale. In operation, the worst-case peak magnetic field condition is not prolonged. This is because train current does not remain at a peak level under all operating conditions, because currents split between two tracks, between running rails and negative feeder, and between current paths to the front and rear front and rear as the train proceeds down the line.

Figure 26-1 shows that a person standing on a station platform, at about 8 ft from the track centerline or 16 ft from the ROW centerline, could be exposed to a worst-case magnetic field of about 720 mG. Thus, the worst-case human exposure is about 7.9 percent of the applicable MPE limit and less than the 1.0 G implanted medical device limit.

Figure 26-1: Worst-Case Magnetic Field due to a 930 A train, close to the track

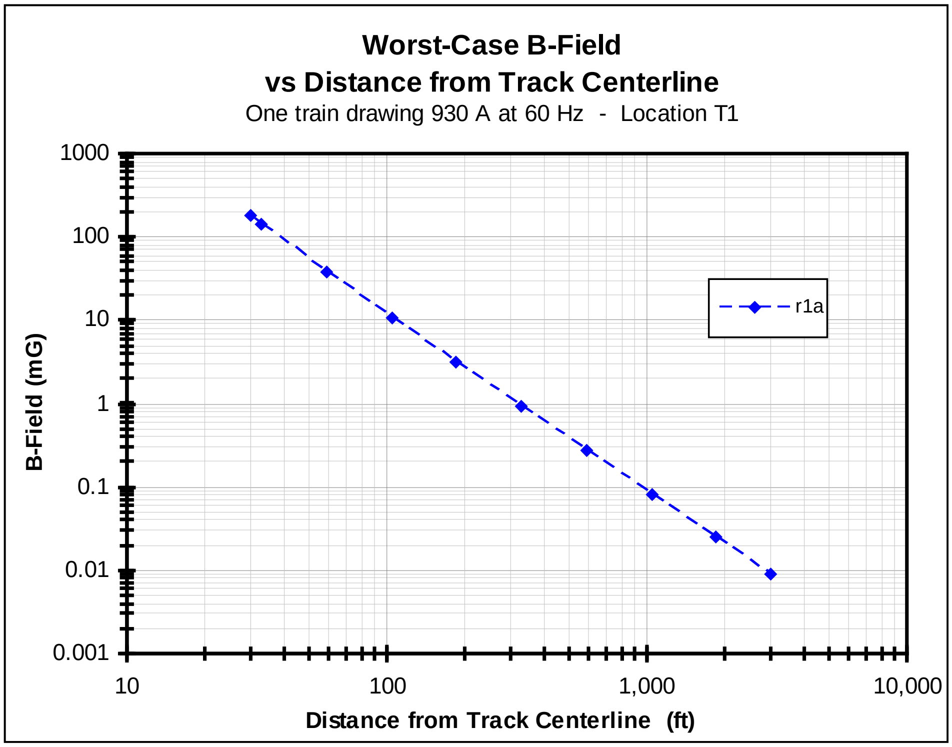
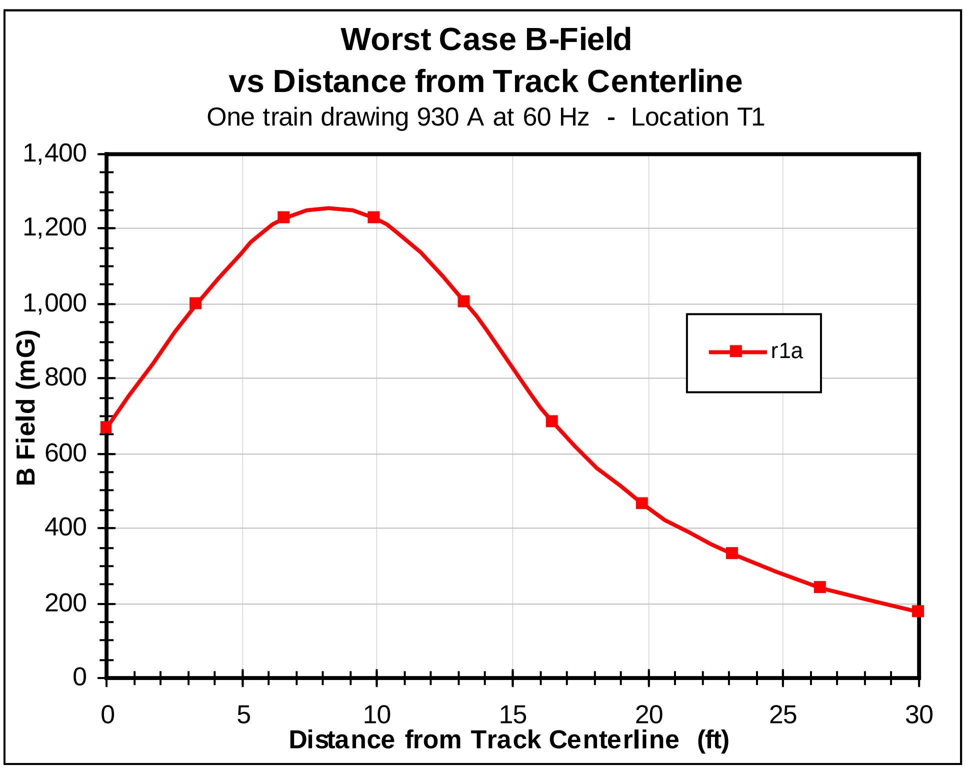


Figure 26-2: Worst-Case Magnetic Field due to a 930 A train, farther from the track



In addition, after construction, EMF levels shall be measured to determine whether actual EMF levels exist above the recommended 1.0G limit at or near the passenger station platform edge, and determine whether passengers or employees with implanted medical devices can be exposed to magnetic fields above the established limit. The measurements shall be made following procedures in EN 50500, Measurement procedures of magnetic field levels generated by electronic and electrical apparatus in the railway environment with respect to human exposure. If the actual EMF levels exceed the established limit, the safety program shall ensure that passengers and employees who have implanted medical devices are informed of the condition by placing suitable warning signs on the passenger station platforms, indicating areas where passengers and employees with pacemakers can stand or sit without exposure to EMF levels above the recommended limits.

The magnetic field MPE limits for general public and controlled environments shall conform to IEEE Std C95.6 Table 2 and IEEE Std C95.1 Tables 2, 8, and 9. The limit for the general public at 60 Hz is 9.0 G.

The static electric field MPE limits for general public and controlled environments shall conform to the IEEE Std C95.1 Table 4, 8, and 9 and IEEE Std C95.6 Table 4.

The propagating EMF MPE limits for general public and controlled environments shall conform to the IEEE Std C95.1 Table 8 and 9. The MPE limits in the cited revisions of the standards shall apply unless the Contractor establishes that a newer revision of the Standard is applicable and that the newer revision of the Standard provides adequate protection to people near the tracks.

Chapter 27

Supervisory Control and Data Acquisition Subsystems

HSR 13-06 - EXECUTION VERSION

Revision	Date	Description
0	02 Mar 12	Initial Release, R0

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Appendix

Appendix 27.A SCADA Command, Monitor and Diagnose Matrix 27-26

Acronyms

AC	Alternating Current
ATC	Automatic Train Control
ATS	Automatic Train Supervision
CHST	*Not Used; use HST for California High-Speed Train*
CHSTP	California High-Speed Train Project
CIC	Communication Interface Cabinet
COTS	Commercial off-the-Shelf
DC	Direct Current
FAC MEP	Facilities Mechanical, Electrical, and Plumbing
FRT	Fixed Remote Telemetry
HDEW	Hazard Detection/Early Warning
HMI	Human Machine Interface
HST	High-Speed Train
HV	High Voltage
HVAC	Heating, Ventilation, and Air Conditioning
IIMP	Integrated Information Management Platform
INF MEP	Infrastructure Mechanical, Electrical, and Plumbing
kV	Killo-Volts
LAN	Local Area Network
MEP	Mechanical, Electrical, and Plumbing
MTU	Master Terminal Unit
PLC	Programmable Logic Controller
PS	Parallel Stations
PTC	Positive Train Control
OCC/RCC	Operations / Regional Control Center
OCS	Overhead Catenary System
ROW	Right of Way
RTU	Remote Terminal Unit
SCADA	Supervisory Control and Data Acquisition
SS	Substation
SWS	Switching Stations
TES	Traction Electrification System
TSR	Temporary Speed Restriction
UPS	Uninterruptible Power Supply
WAN	Wide Area Network
WPC	Wayside Power Control Cubicles

27 Supervisory Control and Data Acquisitions Subsystems

27.1 Scope

The Supervisory Control and Data Acquisition (SCADA) Design Criteria presents the guidelines, principles and processes that must be followed to successfully design and implement SCADA subsystems, software, equipment and support systems for the California High-Speed Train Project (CHSTP). These underlying design criteria govern the design and implementation of SCADA Systems and shall be applied consistently across the entire California High-Speed Train (HST) system.

The SCADA Design Criteria addresses design criteria for all SCADA systems used to support the provisioning, safe operation, and cost-effective operations and maintenance of the HST system. The following SCADA systems shall be designed, built, integrated and tested using these criteria and guidelines to support the requirements of the CHSTP.

This document contains general SCADA guidelines and SCADA subsystem sections that capture SCADA subsystem design criteria and guidelines.

The following SCADA subsystems are the focus of this document:

- Traction Electrification System (TES) SCADA subsystem
- Automatic Train Supervision (ATS) SCADA subsystem
- Hazard Detection/Early Warning (HDEW) SCADA subsystem
- Infrastructure Mechanical Electrical Plumbing (INF MEP) SCADA subsystem
- Facilities MEP (FAC MEP) SCADA subsystem
- Fixed Remote Telemetry (FRT) SCADA subsystem

The on-board monitoring and diagnostics system is not included in the scope of this chapter. For design criteria for interfacing on-board monitoring and diagnostics systems to wayside systems please see the *Rolling Stock-Core Systems Interfaces* chapter.

For each system the following classifications of design criteria are defined:

- **Architecture Design Criteria** – High-level design criteria focused on redundancy, overall subsystem configuration and similar.
- **Spare Capacity, Expansion and Obsolescence Design Criteria** – Design criteria focused on spare capacity, expansion, and obsolescence.

- **Command and Control Design Criteria** – Design criteria focused on how the SCADA subsystem is controlled both locally and remotely. A Control, Monitor and Diagnose matrix is included to show what functionality is controlled by Operations and Maintenance users at local and remote locations.
- **Physical, Enclosure and Power Design Criteria** – Low-level design criteria focused on system components' physical support design criteria including, cabinets, enclosures, Heating, Ventilation, and Air Conditioning (HVAC), power, uninterruptible power supply and similar.
- **End-Device Design Criteria** – Low-level design criteria focused on end-device attributes, placement and characteristics.

27.2 Regulations, Codes, Standards, and Guidelines

Refer to the *General* chapter for requirements pertaining to regulations, codes, and standards.

- Code of Federal Regulations (CFR)
  - Title 47 CFR, Part 15: Class A
  - Title 49 CFR, Part 236 Appendix E: Human-Machine Interface (HMI) Design
- Americans with Disabilities Act (ADA)
  - Title 28, CFR Part 35: Title II Technical Assistance Manual
  - Title 28, CFR Part 36: Title III Standards of Accessible Design
  - Title 49, CFR Part 37: Transport Services for Individuals with Disabilities
- National Fire Protection Association (NFPA) Codes and Standards
  - NFPA 70: National Electrical Code
  - NFPA 72: National Fire Alarm Code
  - NFPA 130: Standard for Fixed Guideway Transit and Passenger Rail Systems
- American National Standards Institute (ANSI) Standards
  - ANSI –J-STD-607-A: Commercial Building Grounding (Earthing) and Bonding Requirements for Telecommunications
  - ANSI/ICEA S-87-640: Standard for Outside Plant Communications Cable
  - ANSI/ICEA S-80-576: Communications Wire and Cable for Wiring of Premises
  - ANSI/ICEA S-83-596: Standard for Fiber Optic Premises Distribution Cable
  - ANSI/HFES 100: Human Factors Engineering Requirements for Visual Display Terminal (VDT) Work Stations

- ANSI/IEEE C37.90.2: Standard for Tolerance of Radiated Electromagnetic Frequency Interference (RFI)

- Institute of Electrical and Electronics Engineers (IEEE) Standards
  - IEEE 802.1: Bridging and Management
  - IEEE 802.3: Ethernet
  - IEEE 802.11: Wireless LANs
  - IEEE 828: Standard for Software Configuration Management Plans
- International Organization for Standardization (ISO) Standards
  - ISO/IEC 12207: Systems and software engineering -- Software life cycle processes
- Electronic Industries Association/Telecommunications Industry Association (EIA/TIA) Standards
  - EIA-310: Cabinets, Racks, Panels, and Associated Equipment
  - EIA 472: Generic Specifications for Fiber-optic cable
  - EIA/TIA-598: Optical Fiber Cable Color Coding
  - TIA-475.0000: Generic Specifications for Fiber Optic Connectors
  - TIA/EIA-455: Standard Test Procedures for Optical Fibers, Cables, Transducers, Sensors, Connecting and Terminating Devices, and other Fiber Optic Components.
  - TIA/EIA 568: Commercial Building Telecommunications Cabling Standards
  - TIA/EIA 569: Commercial Building Standard for Telecommunications Pathways and Spaces
- Underwriter Laboratories Inc. (UL) Publications
  - UL 6: Rigid Metal Conduit
  - UL 44: Thermoset-Insulated Wires and Cables
  - UL 50: Standard for Enclosures for Electrical Equipment
  - UL 62: Flexible Cords and Cables
  - UL 94: Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances
  - UL 467: Grounding and Bonding Equipment
  - UL 486 A-E: Wire Connectors
  - UL 510: Standard for Polyvinyl Chloride, Polyethylene and Rubber Insulating Tape
  - UL 514A: Metallic Outlet Boxes
  - UL 514B: Conduit, Tubing, and Cable Fittings

  - UL 886: Outlet Boxes and Fittings for Use in Hazardous (Classified) Locations
  - UL 1581: Reference Standard for Electrical Wires, Cables and Flexible Cords
  - UL 1778: Uninterruptible Power Supply Equipment
- Telcordia [Bellcore]
  - Network Equipment-Building System (NEBS) LEVEL 3 requirements
  - GR-20: Generic Requirement for Optical Fiber and Optical Cables
  - GR-63: NEBS Requirements: Physical Protection
  - GR-771: Generic Requirements for Fiber Optic Splice Closures
- U.S, Department of Defense (USDOD) Standards
  - MIL-STD-1472: Human Engineering
  - MIL-STD-781: Reliability, Test Methods, Plans, and Environments for Engineering, Development, Qualification and Production
  - MIL-STD-810: Department of Defense Test Method Standard for Environmental Engineering Considerations and Laboratory Tests
- National Transportation Communications for ITS Protocol (NTCIP) Standards
- Telecommunication Standardization Sector (ITU-T) Standards

27.3 Related Documentation

- Design Criteria chapters
  - General
  - Trackway Clearances
  - Utilities
  - Structures
  - Stations
  - Support Facilities
  - Facility Power and Lighting Systems
  - Rolling Stock and Vehicle Intrusion Protection
  - Building Automation and Management Systems
  - Traction Power Supply System
  - Overhead Contact System and Traction Power Return System
  - Grounding and Bonding Requirements

- Automatic Train Control
- Electromagnetic Compatibility and Interference
- Supervisory Control and Data Acquisition Subsystems
- Rolling Stock-Core System Interfaces
- Reliability, Availability, Maintainability and Safety

27.4 Overview of the SCADA Subsystems and Related Communications Systems

27.4.1 SCADA Overview

The SCADA subsystems shall be designed to monitor, acquire, transmit and receive data and control inputs and outputs to control and monitor systems and equipment. The SCADA subsystems provide remote control from manned locations including the Operations Control Center (OCC), Regional Control Center (RCC), Station Control Centers to monitor and control selected equipment via Programmable Logic Controllers (PLCs) or remote terminal units (RTUs).

SCADA subsystems shall be used to control and monitor physical processes, sensors equipment and status and have the following elements.

27.4.1.1 SCADA Master Terminal Units

A SCADA Master Terminal Unit (MTU) shall include the centrally located SCADA subsystem servers, processors, databases and software responsible for communicating with the SCADA subsystem field equipment. (A SCADA MTU is also described as a SCADA headend.) The designer may ultimately choose to combine the several SCADA subsystem MTUs' functionality into a single or multiple MTUs. Within this document, each SCADA subsystem will be described as a stand-alone subsystem with independent MTUs.

27.4.1.2 SCADA Field Equipment

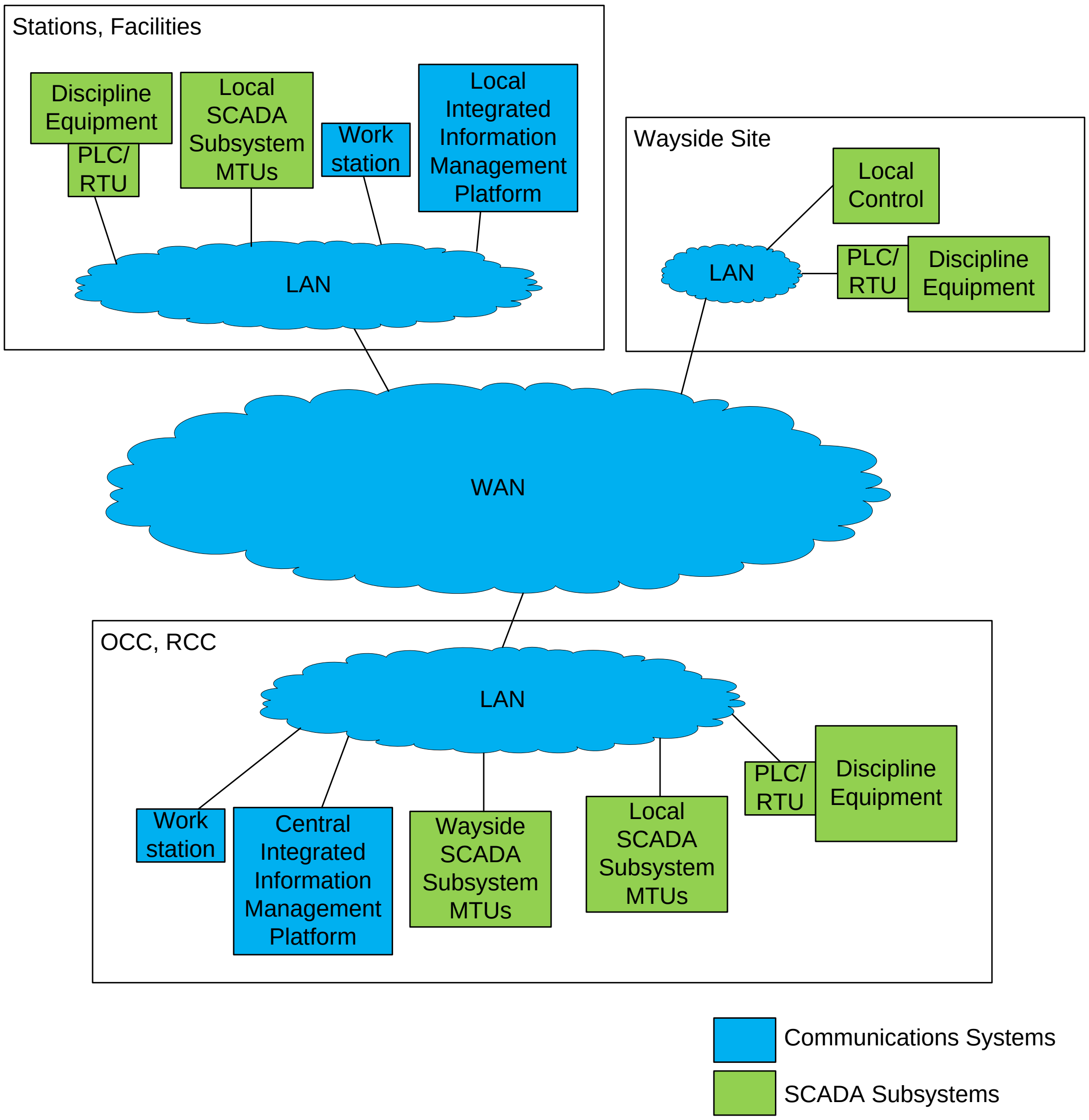
RTUs and/or PLCs are the electrical devices which shall interface between physical plant, equipment or sensors and the communications Wide Area Network (WAN) or Local Area Network (LAN).

SCADA subsystems may also be designed to include local control panels co-located with physical plant, equipment or sensors being controlled or monitored. These local control panels may be a workstation with GUI, or control panel and shall be used to provide local control, monitoring and health diagnosis of the SCADA equipment that is located within the vicinity.

27.4.2 Communications Systems for SCADA Data Transport

The SCADA subsystems shall transmit control signals and alarms between remote sites and the OCC/RCC and locally via the interconnection of communications systems (WAN and LAN) or utilize dedicated cable infrastructure. Figure 27-1 shows the relationship between communications systems and SCADA subsystems elements.

Figure 27-1: SCADA and Communications Systems



27.4.2.1 Wide Area Network and Local Area Networks

Please see *Communications* chapter for descriptions of the WAN and the LAN. It is required that all SCADA subsystem devices using communications data transport systems interface electrically and/or optically on the basis of standardized, accepted and interoperable protocols.

27.4.2.2 Integrated Information Management Platform and SCADA Subsystems

Please see the *Communications* chapter for a description of the Integrated Information Management Platform (IIMP). SCADA data shall be integrated with other data to provide integrated control over all Project systems via the IIMP.

SCADA Human Machine Interface (HMI) functionality shall be provided to give users control and visibility of SCADA subsystem MTU processes such as feedback, trending, diagnostics, and management information such as scheduled maintenance procedures, detailed schematics for a particular sensor or machine, and troubleshooting guides. In general, SCADA data and control shall be displayed and used by operations personnel at the OCC, RCCs, stations, yards and facilities via the communications IIMP while HMI functionality shall be provided by the SCADA subsystem designer. Generally, the IIMP shall only act as the human interface presentation device for the SCADA subsystems; it performs no SCADA processing. HMI functionality shall be designed to present SCADA information to the operating personnel graphically, in the form of a mimic diagram. The IIMP gathers and presents the data provided by the SCADA subsystems' MTUs to automatically or manually allow the operator, dispatcher, security officer, station manager or maintenance manager to control, monitor and diagnose systems. Status reporting, information storage and retrieval, alarm processing, incident and operation reports shall be provided at the OCC/RCCs and other specified access points throughout the system. All SCADA points shall be able to be displayed and controlled, depending on user privileges via the IIMP workstations located throughout the system.

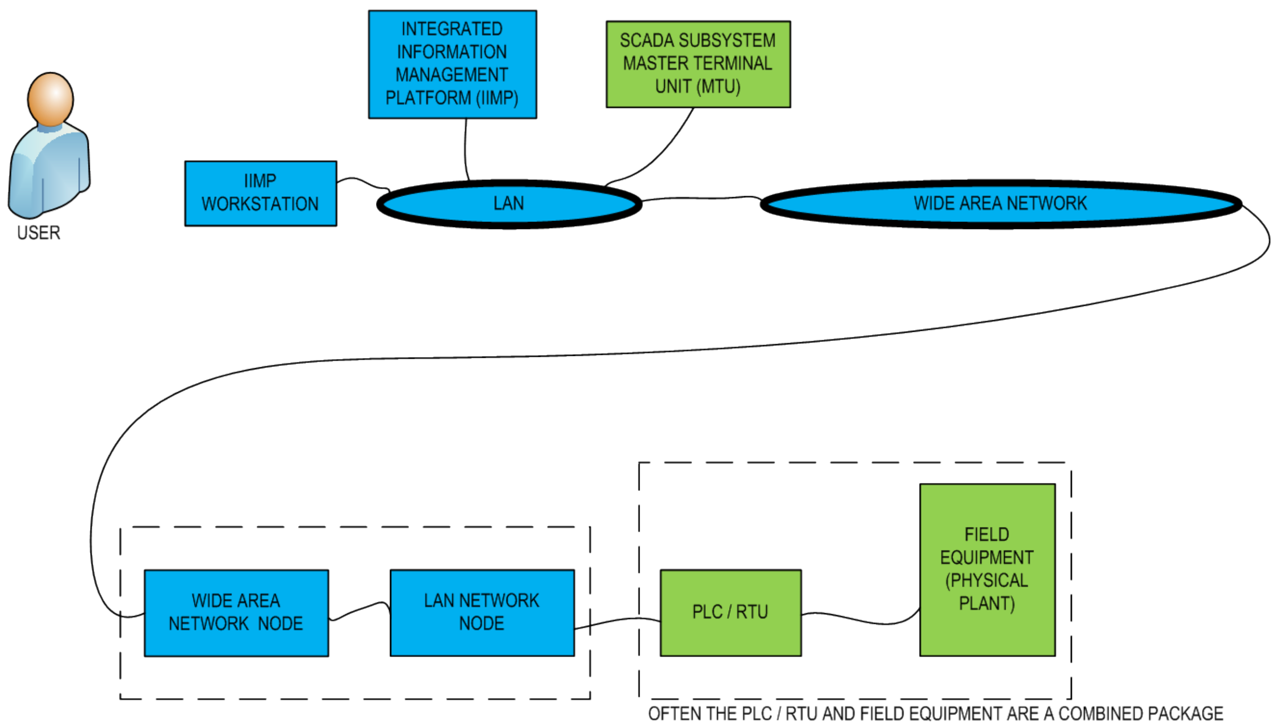
27.4.2.3 SCADA Interfaces

The SCADA subsystems shall be designed to interface with communications systems and other Project systems. The designer is to design the SCADA subsystems to interface with the communications systems. See the *Communications* chapter for details on communications system design criteria.

<u>Wired Interface Chain</u>

The majority of the SCADA subsystems shall be interfaced to the communications systems via wired interfaces.

Figure 27-2: Typical Wired SCADA Subsystem to Communications Systems Interfaces



27.5 SCADA Subsystems

The SCADA subsystem elements shall be designed to be compliant with the protocols and connectivity of the WAN and/or LAN and other communications systems, as appropriate.

27.5.1 General SCADA Subsystems

The SCADA subsystems shall be individual systems that deliver remote command, control and monitoring functionality to the system. The following design criteria sections apply to all SCADA subsystems unless more specific or stringent criteria are listed in the individual sections.

27.5.1.1 General SCADA Subsystems Architecture

The core system designer shall design MTUs for SCADA subsystems to be located at OCC and RCCs. For each SCADA subsystem, there shall be redundancy designed into the failover means for SCADA subsystem MTUs installed at each OCC and RCC. The OCC MTU shall be configured to be the master MTU for each SCADA subsystem, in the event of failure the RCC MTUs shall take over from the main OCC MTU.

The facility and station designer shall design MTUs for Facility MEP and Fixed Remote Telemetry SCADA subsystems to be located at main Train Control & Communications (TCC) rooms at each facility and station.

The adherence to open system architecture concepts and non-proprietary standards is required whenever it is available to ensure interoperability of products from two or more manufacturers.

Standard commercial off-the-Shelf (COTS) devices shall be used when such equipment and materials meet the functional and performance specifications. Special designs and custom assemblies shall be confined to those devices that require such features to assure compliance with the specifications.

27.5.1.2 General SCADA Subsystems Spare Capacity, Expansion and Obsolescence

SCADA subsystem design shall minimize the effects of early component or subsystem obsolescence due to advances in technology.

The SCADA subsystems shall be designed to facilitate future integration of additional facilities without interruption of the already operating system when these additions are implemented.

The SCADA subsystems shall be designed to accommodate a full-scale deployment along the Authority's entire proposed right-of-way. Nothing in the design shall preclude the Authority from expanding the systems via subsequent, open procurements. The SCADA subsystems shall be designed to have a scalable, flexible, open, non-proprietary architecture.

Over and above the above requirement for accommodating a full-scale deployment, the cable infrastructure, SCADA subsystems, enclosures, spaces and support systems (e.g. HVAC, UPS) shall be designed to accommodate the future expansion or installation of 25% additional SCADA subsystems equipment and/or end devices.

27.5.1.3 General Command and Control

The SCADA subsystems shall be designed to meet user requirements and command and control requirements.

Please refer to Appendix 27.A for high-level functionality to be designed into the SCADA subsystem. This high-level functionality is shown in column 1. This matrix also defines the level of control to be designed into the SCADA subsystems for Operations and Maintenance personnel interface. All SCADA subsystem interface functionality to other systems is defined in the specifications.

In general, interfaces and integration between SCADA subsystems and other systems shall be accomplished via the Integration Logic within the communications IIMP. Please see the *Communications* chapter's section on Integrated Information Management Platform.

In general, SCADA subsystems shall be designed to have multiple levels of command and control by users located at OCC, RCC, stations, facilities and yards. Each SCADA subsystem shall be designed to be controlled and accessed via application programming interface (API) by

the appropriate central or local Integrated Information Management Platform (please see the *Communications* chapter) whereby the integration, interface and command and control functionality specified can be controlled via the central and/or local IIMPs.

Each SCADA subsystem shall have self-diagnostics built-in to the system whereby end-devices, inputs and components can be remotely interrogated to determine the health and operational status of the system and speed fault diagnosis and repair in response to failures.

Each SCADA subsystem shall support local initialization and troubleshooting with either a local control panel or portable test equipment.

Each SCADA subsystem shall include specific local and remote command, monitor and diagnose requirements for users with different functions and locations.

27.5.1.4 General SCADA Subsystems Physical, Enclosure and Power

All SCADA Subsystem MTU equipment shall be designed to be enclosed in standardized equipment racks.

Equipment cabinet and enclosure doors shall be equipped with lockable handles. All locks shall be keyed alike. Doors shall be removable when unlocked.

Cabinets within rooms shall be located so that rack mounted equipment can be accessed via the front and the back of the cabinet. Equipment mounted within wall mounted enclosures or cabinets shall be mounted such that both front and rear access to the equipment is possible via swing-out equipment rack mounting.

Each cabinet and enclosure shall have a main breaker that can shut off power to all equipment in the cabinet or enclosure.

Equipment cabinets and enclosures shall be as specified in the *Electromagnetic Compatibility and Interference* chapter.

Cabinets and enclosures that are not located within environmentally and particulate-controlled equipment rooms shall be NEMA-4 rated. These cabinets and enclosures shall be enclosed and lockable and be designed to meet the environmental requirements of the housed equipment.

Normal testing shall not require major disassembly of the equipment under test or of any other equipment.

Remote SCADA equipment shall be equipped for protection from electromagnetic interference levels consistent with location. Bus bars shall be provided for grounding in all SCADA cabinets.

SCADA equipment enclosures, housings, conduit pathways and spaces shall not violate the clearances as specified in the *Trackway Clearances* chapter and shall be spatially coordinated with the requirements in the *Tunnels* and *Structures* chapter.

Loads of SCADA equipment enclosures, housings, conduit pathways and cabling mounted on structures shall not exceed the load limits specified in the *Structures* chapter.

Power and Uninterruptible Power Supply (UPS)

Refer to the *Facility Power and Lighting Systems* chapter for Uninterruptible Power Supply (UPS) details. Uninterruptible power shall be provided to all SCADA subsystems equipment including MTU and field devices based on criteria listed in the *Facility Power and Lighting Systems* chapter.

All SCADA subsystem equipment shall be capable of automatic start-up following a power outage of any length without requiring manual re-initialization.

All SCADA subsystem equipment shall retain full status memory and process recall when operating on power from battery or inverter sources.

27.5.1.5 General SCADA Subsystem End-Devices

The majority of SCADA subsystem field equipment in tunnel areas shall be located in cross passages.

All end-device equipment shall, wherever practical, be designed to contain a self-diagnostic capability to permit the remote interrogation of the health and operational status of the unit and facilitate speedy repair after failure.

All SCADA subsystem end-device equipment shall be mounted in a serviceable location within proximity to the equipment served.

All SCADA subsystem end-device equipment shall perform self-tests upon power-up and on command from local test equipment and from supervisory stations. Self-tests shall also be performed by input/output equipment.

All SCADA subsystem end-device equipment shall provide for maintenance of input/output circuits (including disabling power to output circuits) and safe replacement of input/output cards while power is applied to the remote SCADA equipment.

All SCADA subsystem end-device equipment shall be capable of continued operation in the electromagnetic environment where located, such as traction power facilities, wayside power control cubicles, signal cases, near Overhead Contact System (OCS), in tunnels and trenches and communications equipment rooms.

Remote SCADA equipment shall utilize a network connection to the WAN or LAN for communication with the MTU. The SCADA network interface shall be compliant with the applicable WAN and/or LAN protocols. The SCADA network interface shall be functionally contiguous among all SCADA remote units and the MTU when linked via the WAN, LAN. Error correction and detection schemes shall utilize an industry standard compatible with the WAN and/or LAN.

All SCADA subsystem end-device equipment shall operate normally unattended. Remote SCADA equipment logic and configuration data shall reside in non-volatile memory.

Input and output signals shall be electrically isolated from SCADA equipment.

SCADA end device placement shall not violate the clearances as specified in the *Trackwork Clearances* chapter and shall be spatially coordinated with the requirements in the *Tunnels* and *Structures* chapter. SCADA end device locations shall be coordinated with structural and architectural elements. See *Stations, Support Facilities* and *Structures* chapters.

Loads of SCADA end devices mounted on structures shall not exceed the load limits specified in the *Structures* chapter.

27.5.2 Traction Electrification System (TES) SCADA Subsystem

27.5.2.1 Traction Electrification System and Equipment Introduction

See *Traction Power Supply System* chapter for Traction Electrification System description and details. The details of OCS design criteria are presented in the *Overhead Contact System and Traction Power Return System* chapter.

Table 27-1 is a description of 27.5.2 Traction Electrification System (TES) equipment that is controlled and monitored by TES SCADA and its general location.

Table 27-1: TES Equipment

TES Equipment	Function	General Location
Main transformers	Transform voltage of incoming supply to 2x25 kV	Traction power substations (SS), located roughly 30 miles apart along the ROW
Autotransformers	Boost the OCS voltage	Switching stations (SWS) and paralleling stations (PS) located along the ROW with the configuration SS-PS-Ps-SWS-PS-PS-SS- PS and so on.
HV circuit breakers	To disconnect HV supply under load conditions and for protection of the system	HV side of the traction power substations
HV disconnect switches	To disconnect HV supply under no-load conditions	HV side of the traction power substations
25 kV circuit breakers	To disconnect 25 kV supply under load conditions and for protection of the system	At all SS, SWS, PS and at interlockings
Motorized disconnect Switches	To disconnect 25 kV supply under no-load conditions	At all SS, SWS, PS, at railway stations, wayside universal crossovers, maintenance facilities, tunnel portals, and in tunnels longer than three miles

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27.5.2.2 Description of the TES SCADA Subsystem

The TES SCADA system monitors and controls remote data input/output units to and from the user control locations and TES equipment. TES equipment is located at Traction Power Facilities: SS, SWS, PS and Wayside Power Control Cubicles (WPC). Field TES SCADA equipment shall be installed at these locations. The TES SCADA system shall comprise MTUs located at the OCC and RCCs and remote TES SCADA equipment located in the field at TP Facilities. Communications between the MTUs and the remote SCADA equipment shall utilize the communications WAN and LANs and the appropriate communications protocols.

The TES SCADA subsystem shall provide supervisory control of the TES. The TES SCADA system shall transmit in real-time: metering data, indications, alarms, and controls and confirmation thereof between wayside facilities and equipment and the MTUs located at the OCC and RCCs via the WAN and LANs. These SCADA transmissions shall include:

- Metering information
- TES alarm and control signals and status indications
- TES related auxiliary and emergency power alarms and signals
- Status reports, information storage and retrieval, alarm processing, incident and operations reports shall be provided by the MTUs

27.5.2.3 TES SCADA Subsystem Architecture

The TES SCADA subsystem shall be designed to achieve the following operational objectives:

- Permit complete control of the TES.
- Indicate unambiguously the position of every controllable circuit breaker and switch on the TES and the status of equipment and/or subsystems.
- Indicate the value of pre-determined analog quantities.
- Provide an alarm condition if some preset value is exceeded.
- Provide an alarm condition if a circuit breaker is automatically operated due to a fault condition.
- Provide an alarm if an unintentional operation takes place.
- Indicate geographically the electrical condition (i.e. energized, isolated or grounded) of the TES.
- Perform routine tests at any time to verify that the equipment is in correct working order, without interfering with the wiring and without removal of any primary/on-line and/or secondary/"hot-standby" equipment.

The TES SCADA subsystem shall be based upon an open modular architecture approach, which is compliant with the Open Software Foundation Distributed Computing environment for

distributed computing functions and totally portable among hardware platforms of different origin.

The TES SCADA subsystem shall be modular to permit expandability for future extensions to the TES and future non-TES applications.

The TES SCADA subsystem shall be designed to:

- Be capable of transmitting digital status and control data, and analog measurement data.
- Be self monitoring (i.e. failure of any piece of equipment down to the individual printed circuit boards shall cause an alarm locally and at the MTUs).
- Incorporate hardware and/or software features that prevent access by unauthorized persons.
- Employ industry standards for network interfaces (i.e. hardware and software).
- Be capable of archiving and retrieving information over a time span up to 5 years.
- Permit the generation of pre-configured and customized reports.
- Be compatible with the Train Control System and Hazard Detection/Early Warning SCADA subsystem and permit data exchange in real time (*the information to be exchanged will be defined by CHSTP during the design phase*).
- Be immune to Electromagnetic Interference (EMI) from nearby high current electrical equipment to ensure safe and reliable operations under all loads and faults.
- Be designed such that replacement of components can be performed easily in the field.

Standard industry-accepted open and non-proprietary network communication protocols compatible with the WAN and LAN design and field communications protocols (between network and field equipment) shall be used.

Operating and application software shall be used that is compliant to industry standards produced by standard organizations, as specified in the *Communications* chapter.

Duplicate redundant communication, processing, power supply equipment, and input/output interface components, necessary as part of the TES SCADA subsystem, shall be provided at each traction power facility, WPC and at the OCC and RCCs.

The hardware or software failure of one unit, major or minor, including nodes common to primary/on-line and secondary/"hot-standby" equipment shall not cause complete failure of its associated equipment or any other equipment.

All secondary/"hot-standby" equipment shall be continuously monitored to the same extent as the primary/on-line equipment.

All processing equipment shall be individually addressable.

The TES SCADA equipment shall be capable of accommodating variations (without degradation in communications) in line impedance, delay distortion, etc., which may be expected on these types of circuits

Failure of the SCADA software or hardware shall not create a less safe condition. Indication of such a loss shall be provided at the OCC/RCC.

27.5.2.4 TES SCADA Subsystem Spare Capacity, Expansion and Obsolescence

The SCADA system's hardware and software shall be sized to include 25% percent spare equipment and points and 100% system expandability for future growth and expansion of the TES.

27.5.2.5 TES SCADA Subsystem Command and Control

Please refer to the Command, Monitor and Diagnose matrix in Appendix 27.A for TES SCADA high-level functionality and Command, Monitor and Diagnose criteria.

At the OCC/RCC, all alarms shall be required to be acknowledged by the central control operator, before they are cleared from the SCADA's alarm summary list at the user interface.

At each user interface, a full-featured software program for defining and controlling user access to the SCADA system shall be provided. The system administrator shall define access capabilities for each user, user interface and each SCADA application and support function via access control displays.

The user interface displays shall mimic the system single line diagrams and equipment symbols depicted on design documentation, including equipment and cable designations:

- Energized and de-energized power equipment and/or conductors (i.e. circuit breakers, disconnect switches, 25 kV feeder and OCS circuits) shall be depicted by red and green respectively.
- Operational and non-operational communication equipment and fiber optic cables shall be depicted by blue and green respectively.
- Equipment that is switched to local control shall be depicted by a unique, user-defined color.
- Equipment locked and tagged out by the power dispatcher shall be indicated by a unique, user-defined color.

One local control panel user interface shall be provided at each traction power facility control and relay room equipment enclosure.

No permanent user interface is required at WPC. However the local TES SCADA equipment shall include the provision to interface a laptop computer to interface and control, monitor and diagnose local SCADA functionality when necessary.

The TES SCADA subsystem shall not monitor and/or control equipment owned, operated and maintained by the local power utility company but shall monitor the voltage on the HV side of the main transformers at the traction power substations.

The TES SCADA subsystem must provide local and remote SCADA command and control functionality of TES equipment at the following field locations:

- Traction Power Substations
- Traction Power Switching Stations
- Traction Power Paralleling Stations
- Wayside Circuit Breakers and Motorized Disconnect Switches
- Wayside Power Control Cubicles

Each piece of similar equipment shall be individually monitored and/or controlled.

A failure in the primary and/or secondary SCADA equipment shall annunciate an event alarm.

27.5.2.6 TES SCADA Subsystem Physical, Enclosure and Power

Equipment associated with the TES SCADA subsystem shall be located in secured enclosures and/or rooms to prevent unauthorized access.

TES SCADA equipment at traction power facilities (TPF) and WPC shall be housed in dedicated enclosures that can be incorporated into an equipment line-up or wall mounted.

The TES SCADA equipment at the OCC/RCC shall be powered from normal and UPS. The SCADA equipment at trackside facilities shall be powered from a battery or from an integral battery-backed power supply with preferred voltage of 24 V dc; or a 125 V dc control power source.

120 V ac circuits to TES SCADA equipment shall not provide power to other subsystems. Additionally primary/on-line and secondary/“hot-standby” equipment shall not be fed from the same 120 V ac circuit.

All equipment, including mother boards or back planes shall be so arranged as to be readily accessible for inspection, maintenance, fault finding, and repair.

When the emergency power source is activated due to loss of normal power, an event alarm shall be annunciated.

Where a UPS is utilized the following alarms shall be annunciated:

- UPS Loss of Incoming AC Power
- UPS Low Battery Reserve
- UPS Rectifier Failure

- UPS Automatic Switch to Bypass Mode
- UPS Manual Switch Set to Bypass Mode
- UPS Switch to Bypass
- UPS Switch to On-line

Metering functions shall be continuous and all other SCADA points shall be binary (two-state).

27.5.2.7 TES SCADA Subsystem End-Devices

There are no specific criteria. See Section 27.5.1.5.

27.5.3 Automatic Train Supervision SCADA Subsystem

27.5.3.1 Automatic Train Supervision System and Equipment Introduction

The signaling and train control system shall be collectively known as the Automatic Train Control (ATC) system. ATC includes all the safety critical and non-safety critical functions of a train control system, and includes all Positive Train Control (PTC) functions. See *Automatic Train Control* chapter for ATC system description and details.

27.5.3.2 Description of the Automatic Train Supervision SCADA Subsystem

The Automatic Train Supervision system (ATS) shall provide the remote supervision and remote control facilities for the ATC system. Many of the functions including route setting, junction management, and schedule regulation shall have automated functional options with the ability for dispatchers and managers to intervene as necessary.

ATS shall provide the following centralized control and supervision functions (ATS functionality, subsystem performance, and hardware requirements shall be part of the ATC system):

- ATC shall be controlled, supervised, and monitored by ATS from the Operations Control Center (OCC) or the Regional Control Centers (RCCs).
- Train routing – The ATS shall provide automatic and remote manual control of interlockings, including route setting and canceling, and individual switch operation. Automatic train routing shall provide sub-modes including:
  - By schedule
  - By first come first served
  - By train run ID
- Dispatching shall be achieved by the clearing of signal routes for trains about to depart, allowing sufficient time for last minute passengers to board and the doors to close and lock. Signals or movement authorities shall be held against trains to prevent them from departing stations and yards early.

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- Scheduling – The ATS shall store multiple versions of the operating schedule and allow real-time editing by dispatchers and operating supervisors, to cancel, add, or adjust trip information for individual and groups of trains. The ATS shall automatically regulate trains in accordance with the timetable amended or otherwise.
- Temporary Speed Restrictions (TSRs) and work zones shall be entered at ATS workstations and shall be transmitted to and implemented in the field and on-board by the respective ATC subsystems.
- Access to the ATS and its functional layers shall be password protected. Management of functions to layers and of passwords shall be performed by a System Administrator, Chief Dispatcher or equivalent.
- ATS facilities shall be provided in the OCC, RCCs, and training facilities to allow for playback and related analysis of events following incidents and emergencies using ATS recorded data and for training dispatchers and managers.
- ATS facilities shall be provided to enable the training of dispatchers and managers. The simulator functions shall allow the creation of scenarios both from scratch and from recorded data by a trainer. They shall allow the trainee to manage the scenario through to a conclusion. A separate set of workstations shall be provided for training purposes. The training facilities shall also be available for playback of events and incidents.
- ATS facilities shall be provided to enable construction and evaluation by simulation of new timetables including supplements to existing timetables and for minor and major editing of existing timetables.
- ATS shall interface to passenger information facilities including customer information signs and audible public address subsystems with train status information for display at passenger stations and other public locations.

27.5.3.3 Automatic Train Supervision SCADA Subsystem Architecture

The ATS shall also provide event recording facilities of all data input to the system and commands sent from the system.

ATC shall provide an automatic field-fallback mode for all interlockings when unsupervised by ATS, except for terminals and major through stations including Los Angeles. In the event of loss of ATS control from the OCC or RCCs, routes at interlockings shall automatically revert to previously programmed through routes and fleet settings, or as otherwise commanded from a Local Control Panel.

All ATS equipment needed for standalone operation shall be installed in the OCC and in at least two additional RCCs.

The ATS subsystem architecture shall be highly availability and reliable, in order to ensure that the ATC and CHSTP meet its service dependability requirements.

ATS hardware shall consist to the maximum extent possible of COTS devices and components. Hardware shall be chosen based on its suitability to the environment in which it will operate and also to facilitate future upgrades of hardware as the COTS equipment becomes obsolete.

The ATS shall contain the equivalent of PTC back office server (BOS) functionality so as to communicate with Interoperable Train Control (ITC) PTC-equipped locomotives and cab cars operating on shared tracks. The BOS shall send safety- and operation-critical database information including temporary changes such as speed limits and established work zones when requested to by an ITC-equipped locomotive approaching the shared track territory.

27.5.3.4 Automatic Train Supervision SCADA Subsystem Spare Capacity, Expansion and Obsolescence

There are no specific criteria. See Section 27.5.1.2.

27.5.3.5 Automatic Train Supervision SCADA Subsystem Command and Control

Under normal conditions, the OCC shall have overriding command and control. Staff at the RCCs may supervise and dispatch trains on their respective shared corridors and the OCC staff can supervise and dispatch trains in all other sections of the system.

Any and all control, supervision, and monitoring functions shall be possible from any workstation within the OCC or RCCs, once authorized with password protected configuration setting functions. Servers and other processors shall be distributed such that the loss of any and all equipment at one of the Control Centers shall not prevent either of the remaining Control Centers from supervising and controlling any part of the CHSTP.

Remote workstations giving access to indications and limited command sets shall be installed in station control rooms, equipment and Maintenance of Infrastructure facilities.

Regional control of each workstation shall be definable by the System Administrator. Definition of access to each set of functional levels shall be password protected.

A Local Control Panel shall also be provided in the interlocking control house for emergencies and for maintenance testing needs.

A Local Control Panel or panels shall also be provided in station control rooms to allow operating personnel to set and cancel routes in the event of a failure of ATS communications between the field sites and the OCC and RCCs or in any other special case by approval from the main dispatcher.

The ATS system shall interface with other systems including the following:

- Traction Power SCADA to enable blocking of track sections to approaching trains in the event that power is off in specific sections
- Facilities SCADA, including fans and pumps to provide remote indications on the dispatcher ATS workstations

- Tunnel facilities SCADA to provide remote indications on the dispatcher ATS workstations
- Event and incident detectors to provide remote indications on the dispatcher workstations
- Yard ATC for the transition of trains between the yards and main tracks and vice versa
- Customer Information and Public Address Systems

The ATS subsystem may be implemented as part of an integrated control system and the functions may be implemented on a common hardware platform to SCADA, security, and other control and command systems.

Please refer to the Command, Monitor and Diagnose matrix in Appendix 27.A for ATS SCADA high-level functionality and Command, Monitor and Diagnose criteria.

27.5.3.6 Automatic Train Supervision SCADA Subsystem Physical, Enclosure and Power

Power for the ATS subsystems shall be redundant and backed up by a combination of batteries (4 hours) and diesel generator (continuous).

27.5.3.7 Automatic Train Supervision SCADA Subsystem End-Devices

There are no specific criteria. See Section 27.5.1.5.

27.5.4 Hazard Detection/Early Warning SCADA Subsystem

27.5.4.1 Hazard Detection/Early Warning System and Equipment Introduction

Hazard Detection/Early Warning (HDEW) sensors are distributed throughout and installed to detect conditions caused by man-made or natural events that can negatively impact the safe and timely operation of the HST. In many cases these sensors shall be designed into structures, fences, infrastructure or other physical elements and features of the CHSTP.

The HDEW sensors shall consist of a variety of formats and types, some may be electrical or fiber optic stress and strain gauges, some may be standard electro-mechanical sensors and others may be gas sensors depending upon the type of data gathered.

27.5.4.2 Description of the Hazard Detection/Early Warning SCADA Subsystem

The HDEW SCADA Subsystem shall be designed to gather the data outputs of the varied HDEW sensors and transmit those indications to the MTUs at various control centers, local locations and IIMPs. The HDEW SCADA subsystem shall provide indication to operations personnel and other relevant systems of potential impacts.

27.5.4.3 Hazard Detection/Early Warning SCADA Subsystem Architecture

There are no specific criteria. See Section 27.5.1.1.

27.5.4.4 Hazard Detection/Early Warning SCADA Subsystem Spare Capacity, Expansion and Obsolescence

There are no specific criteria. See Section 27.5.1.2.

27.5.4.5 Hazard Detection/Early Warning SCADA Subsystem Command and Control

Please refer to the Command, Monitor and Diagnose matrix in Appendix 27.A for HDEW SCADA high-level functionality and Command, Monitor and Diagnose criteria.

Table 27-2: Hazard Detection/Early Warning System Sensors and Equipment

HDEW Sensors	Function	General Location
Earthquake and seismic activity	Detect seismic activity	Seismic sensors are located at all traction power facilities
Excessive winds	Detect wind intensity and speed	At appropriate wayside locations
Flood/Excessive precipitation	Detect high water, snow or flood	At appropriate wayside locations
Structural Hazard	Detect stressed, struck, fatigued or failing aerial track structures	At all aerial structures
Erosion (how is this accomplished?)	Erosion around aerial structures	At all aerial structures
Wildfire	Detect wildfire conditions	At appropriate wayside locations
Right-of-Way Intrusion	Detect when external trains operating in shared corridors have derailed and are encroaching on the Authority's right-of-way creating an unknown or unsafe condition	At shared corridor locations
Underground Air monitoring	In underground tunnels or stations (unlikely), sensors shall detect CO and other unsafe gasses	At all underground locations
Rock fall, Mudslide, Landslide	Detect rock, mud, or earth which has encroached on the Authority's right-of-way creating an unknown or unsafe condition	At appropriate wayside locations
Static Asset Monitoring (longitudinal and transversal fiber optic strain and tension sensors, accelerometers, thermocouples)	Continuous aerial health monitoring system: • Static: – Observe the maximum strain and stresses – Verify cracking, if any – Report strain changes, both during construction and during service	All aerial sections including bridges.

	• Dynamic: – Evaluate the fundamental frequencies, modes and damping ratios – Evaluate the dynamic effects of trains crossing the bridge – Evaluate the long-term changes in the bridge's dynamic properties.	

27.5.4.6 Hazard Detection/Early Warning SCADA Subsystem Physical, Enclosure and Power

HDEW SCADA end devices may be located in harsh and remote environments. SCADA end devices shall be designed to be operated by UPS power and Power over Ethernet (if appropriate), which also must be powered by a UPS source. If the HDEW SCADA end devices are sufficiently remote, the end-device may be powered by solar power and battery backup.

27.5.4.7 Hazard Detection/Early Warning SCADA Subsystem End-Devices

There are no specific criteria. See Section 27.5.1.5.

27.5.5 Infrastructure Mechanical Electrical Plumbing (MEP) SCADA Subsystem

27.5.5.1 Infrastructure MEP Systems and Equipment Introduction

The Infrastructure Mechanical, Electrical, and Plumbing (INF MEP) SCADA subsystem shall monitor and control all of the non-building/non-facility MEP equipment including all MEP equipment within tunnels and trenches. There are multiple mechanical, electrical and plumbing systems supporting the HST in non-facility locations. This equipment is listed in Table 27-3.

Table 27-3: Infrastructure MEP Equipment

INF MEP Equipment	Function	General Location
Sump Pumps	Pump water from low lying areas	Low lying areas within tunnels
Standpipe Valves	Control water flow to standpipes	Tunnels
Fire Isolation Valves	Control water flow to fire fighting water feeds	Tunnels
Fire Suppression (not Fire Alarm)	Controls water flow to sprinkles	Tunnels and wayside structures at sites
Tunnel Ventilation Fans	Used for ventilation, fire control and safety	Tunnels
HVAC	Control environmental status within structures and possibly within tunnels via chilled water	Wayside structures and Tunnels
Electrical devices and circuit breakers	Delivers electricity and protects against faults	Tunnels and wayside structures at sites

Plumbing Meters and Valves	Control water flow to miscellaneous plumbing devices and feeds	Tunnels
Lighting Inverters and Breakers	Provides lighting to underground and enclosed areas	Tunnels and wayside structures at sites
Centralized UPS and Generators not integrated with systems equipment.	Provides uninterruptible power to systems and other sensitive equipment	Tunnels and wayside structures at sites

27.5.6 Facilities Mechanical Electrical Plumbing (FAC MEP) SCADA Subsystem

27.5.6.1 Facilities MEP Systems and Equipment Introduction

The Facility MEP (FAC MEP) SCADA subsystem shall monitor and control the building/facility MEP equipment and building status. The Facilities MEP systems provide mechanical, electrical and plumbing services for the facilities.

Table 27-4: Facilities MEP Equipment

Facility MEP Equipment	Function	General Location
Elevators	Vertical Conveyance	Stations
Escalators	Vertical Conveyance	Stations
Electrical and circuit breakers	Delivers electricity and protects against faults	Stations and Facilities
Hydrogen Detection	Detects unsafe conditions within battery rooms	Battery Rooms
Uninterruptible Power Supplies	Provides uninterrupted power to critical equipment	Stations and Facilities
High/low temperature	Senses extreme room temperatures in critical rooms	Critical communications and other equipment rooms and control rooms
HVAC	Controls climate, within rooms	Stations and Facilities
High humidity	Senses extreme room humidity in critical rooms	Critical communications and other equipment rooms and control rooms
Water detection	Senses water level in critical rooms	Critical communications and other equipment rooms and control rooms

27.5.6.2 Description of the Facilities MEP SCADA Subsystem

The FAC MEP SCADA Subsystem shall be designed to gather the data outputs and provide programmed control of the varied facility equipment and plants. Remote data shall be transmitted to the MTUs at various control centers, local locations and IIMPs.

The FAC MEP SCADA subsystem shall provide local and remote control for all Facility MEP plants, equipment and hardware. The FAC MEP SCADA subsystem shall be a component system of the Building Automation System as described in the *Building Automation and Management Systems* chapter.

27.5.6.3 Facilities MEP SCADA Subsystem Architecture

There are no specific criteria. See Section 27.5.1.1.

27.5.6.4 Facilities MEP SCADA Subsystem Spare Capacity, Expansion and Obsolescence

There are no specific criteria. See Section 27.5.1.2.

27.5.6.5 Facilities MEP SCADA Subsystem Command and Control

Please refer to the Command, Monitor and Diagnose matrix in Appendix 27.A for FAC SCADA high-level functionality and Command, Monitor and Diagnose criteria.

27.5.6.6 Facilities MEP SCADA Subsystem Physical, Enclosure and Power

There are no specific criteria. See Section 27.5.1.4.

27.5.6.7 Facilities MEP SCADA Subsystem End-Devices

There are no specific criteria. See Section 27.5.1.5.

27.5.7 Fixed Remote Telemetry (FRT) SCADA Subsystem

27.5.7.1 Fixed Remote Telemetry Sensors and Equipment Introduction

The Fixed Remote Telemetry sensors shall provide detection of faults and control of miscellaneous electronic equipment.

Table 27-5: Fixed Remote Telemetry Equipment

FRT MEP Equipment	Function	General Location
Electronic Equipment without alarms	Misc	Stations, facilities and wayside
Fare Collection Equipment	Sell fares and manage paid and unpaid borders.	Stations
Power Supplies Dedicated to Equipment (outside of the Electrical System)	Provide dc or ac power to equipment	Generally located within communications rooms, closets, cabinets and CICs
Shelter and Radio Tower Misc equipment (lightning arrestors, tower lights, and similar)	Provide miscellaneous monitoring and safety functions	Wayside shelters and radio towers

27.5.7.2 Description of the Fixed Remote Telemetry SCADA Subsystem

The Fixed Remote Telemetry SCADA Subsystem shall provide remote monitoring and control for miscellaneous equipment deployed throughout the HST system. Monitoring by this SCADA system may include distributed power supplies and rectifiers and similar equipment that have no built-in telemetry functions.

27.5.7.3 Fixed Remote Telemetry SCADA Subsystem Architecture

There are no specific criteria. See Section 27.5.1.1.

27.5.7.4 Fixed Remote Telemetry SCADA Subsystem Spare Capacity, Expansion and Obsolescence

There are no specific criteria. See Section 27.5.1.2.

27.5.7.5 Fixed Remote Telemetry SCADA Subsystem Command and Control

Please refer to the Command, Monitor and Diagnose matrix in Appendix 27.A for FRT SCADA high-level functionality and Command, Monitor and Diagnose criteria.

27.5.7.6 Fixed Remote Telemetry SCADA Subsystem Physical, Enclosure and Power

There are no specific criteria. See Section 27.5.1.4.

27.5.7.7 Fixed Remote Telemetry SCADA Subsystem End-Devices

There are no specific criteria. See Section 27.5.1.5.

Appendix 27.A SCADA Command, Monitor and Diagnose Matrix

The matrix defines the high-level Operation and Maintenance Control, Monitor and Diagnose SCADA functionality for each SCADA subsystem.

SCADA Monitoring Points to be defined by Infrastructure and Systems Team

Command, Monitor and Diagnose to be defined by Operations and Maintenance Team

CHST SCADA Control, Monitor and Diagnose Matrix

This matrix shows what local and remote control, monitoring and diagnosis SCADA functionality is required for CHSTP

C = CONTROL. UNLIMITED OR LIMITED CONTROL AND MONITORING (EXCEPT HEALTH). READ / WRITE

M = MONITOR. ONLY MONITORING OF CONTROL STATUS. READ ONLY

D = DIAGNOSIS. ONLY MONITORING OF HEALTH STATUS, FOR MAINTENANCE. READ ONLY

	Operations Control Center (OCC)								Regional Control Center (OCC)									Terminal Operating Center (TOC)			Yard Operating Center (YOC)		Station Control Room (SCR)	Local (Traction Power Facility)	Local
SCADA MONITORING POINTS	DOC	DDOC	POC	TD	IOC	SOC	ROC	PIC	CMC	DOC	DDOC	POC	TD	IOC	SOC	ROC	PIC	CMC	TM	ATM	PAA	YDM	YTD	STD		Control Panel at Equipment
TRACTION ELECTRIFICATION SCADA SUBSYSTEM																										
Traction Power Substations																										
Watts			M									M													M	D
Kilowatt-Hours			M									M													M	D
Kilovar-Hours			M									M													M	D
Amperes - line and feeder currents			M									M													M	D
Kilovolts - line and bus voltages			M									M													M	D
Kilovolts - power utility voltage			M									M													M	D
115/230 kV Disconnect Switch (see note 1 of Section 9.2.6)			M									M													M	D
115/230 kV Circuit Breaker (see note 1 of Section 9.2.6)			C									C													C	D
115/230 kV Circuit Breaker Pressure Low (see notes 1 and 6 of Section 9.2.6)			C									C													C	D
Transformer Temperature 1st Stage (see note 1 of Section 9.2.6)			M									M													M	D
Transformer Temperature 2nd Stage (see note 1 of Section 9.2.6)			M									M													M	D
Transformer Door Open (see note 1 of Section 9.2.6)			M									M													M	D
Transformer's Automatic On-load Tap Changers (see note 1 of Section 9.2.6)			M									M													M	D
Transformer Oil Pressure (see note 1 of Section 9.2.6)			M									M													M	D
Transformer Oil Level (see note 1 of Section 9.2.6)			M									M													M	D
Transformer Fans On (see note 1 of Section 9.2.6)			M									M													M	D
25 kV Main Circuit Breaker (see note 1 of Section 9.2.6)			C									C													C	D
25 kV Tie Circuit Breaker (see note 1 of Section 9.2.6)			C									C													C	D
25 kV Feeder Circuit Breaker (see note 1 of Section 9.2.6)			C									C													C	D
25 kV Disconnect Switch (see note 1 of Section 9.2.6)			C									C													C	D
SCADA System Alarm (see note 2 of Section 9.2.6)			M									M													M	D
Communication System Alarm (see note 2 of Section 9.2.6)			M									M													M	D
Auxiliary Power Alarm (see notes 3 and 4 of Section 9.2.6)			M									M													M	D
Emergency Power Alarm (see notes 3 and 4 of Section 9.2.6)			M									M													M	D
Remote Control			C									C													M	D
Local Control			M									M													C	D
Protection Relay Indication			M									M													M	D
125 V dc System Trouble Alarm			M									M													M	D
24 V dc System Trouble Alarm			M									M													M	D
Traction Power Substation Trouble Alarm			M									M													M	D
Traction Power Switching and Paralleling Stations																										
Kilovolts - 25 kV ac line and bus voltages			M									M													M	D
Transformer Temperature 1st Stage (see note 1 of Section 9.2.6)			M									M													M	D
Transformer Temperature 2nd Stage (see note 1 of Section 9.2.6)			M									M													M	D
Transformer Door Open (see note 1 of Section 9.2.6)			M									M													M	D
Transformer Oil Pressure (see note 1 of Section 9.2.6)			M									M													M	D
Transformer Oil Level (see note 1 of Section 9.2.6)			M									M													M	D
Transformer Fans On (see note 1 of Section 9.2.6)			M									M													M	D
25 kV Main Circuit Breaker (see note 1 of Section 9.2.6)			C									C													C	D
25 kV Tie Circuit Breaker (see note 1 of Section 9.2.6)			C									C													C	D
25 kV Feeder Circuit Breaker (see note 1 of Section 9.2.6)			C									C													C	D
25 kV Disconnect Switch (see note 1 of Section 9.2.6)			C									C													C	D
SCADA System Alarm (see note 2 of Section 9.2.6)			M									M													M	D
Communication System Alarm (see note 2 of Section 9.2.6)			M									M													M	D
Auxiliary Power Alarm (see notes 3 and 4 of Section 9.2.6)			M									M													M	D
Emergency Power Alarm (see notes 3 and 4 of Section 9.2.6)			M									M													M	D
Remote Control			C									C													M	D
Local Control			M									M													C	D
Protection Relay Indication			M									M													M	D
125 V dc System Trouble Alarm			M									M													M	D
24 V dc System Trouble Alarm			M									M													M	D
Station Trouble Alarm			M									M													M	D
Overhead Contact System (OCS) (under the control of TES SCADA subsystem)																										
Wayside Circuit Breaker at the Interlocking (see note 1 of Section 9.2.6)			C									C													C	D
Wayside 25 kV Motorized Disconnect Switch (see note 1 of Section 9.2.6)			C									C													C	D
Wayside Power Control Cubicles (WPC)																										
SCADA System Alarm (see note 2 of Section 9.2.6)			M									M													M	D
Communication System Alarm (see note 2 of Section 9.2.6)			M									M													M	D
Auxiliary Power Alarm (see notes 3 and 4 of Section 9.2.6)			M									M													M	D
Emergency Power Alarm (see notes 3 and 4 of Section 9.2.6)			M									M													M	D
Battery Trouble Alarm			M									M													M	D
WPC Trouble Alarm - e.g. thermostat, vent fan failure etc.			M									M													M	D
Stray Current Monitoring																										
Stray Current Condition Detected!!			M									M													M	D
Automatic Train Supervision SCADA Subsystem																										
TBD																										

1

Systems & Infrastructure Input

Operations and Maintenance Input

HAZARD DETECTION / EARLY WARNING SCADA SUBSYSTEM																										
Earthquake and seismic activity																										
Earthquake Detected																										
Fault Crossings - small displacement																										
Fault Crossings - large displacement																										
Wind																										
Excessive Wind Speed Detection																										
Excessive precipitation (Is CHST likely to have flooded tracks?)																										
Flooding Detection																										
Erosion (around aerial structures. How is this detected?)																										
Erosion Detection																										
Structural Hazards																										
Object or debris falling or thrown from overpass Detected																										
Underpass Strike																										
Wildfire (At selected locations)																										
Fire Detected																										
Right of Way Intrusion																										
Intrusion Shared Corrider Detected																										
Intrusion Highway Detected																										
Underground Air Monitoring																										
Methane Detected																										
Carbon Monoxide Detected																										
Hydrogen Sulfide Detected																										
Nitrogen Dioxide Detected																										
Natural Gas Detected																										
Rockfall, Mudslide, Landslide																										
Intrusion Detected																										
Static Asset Monitoring (Crucial Structures)																										
Tension, Accelerometrics, Temperature																										
Infrastructure MEP SCADA Subsystem																										
Mechanical																										
FIRE-FIGHTERS AIR REPLEMISHMENT SYSTEM																										
FIRE SUPPRESSION SYSTEM (different from Fire Alarm System)																										
VENTILATION SYSTEM for Jet or Axial Fans																										
Tunnel Air cooling system (if required)																										
HVAC in shelters																										
COMPRESSED AIR SYSTEM																										
Electrical																										
Circuit Breakers Status																										
Electrical Status, Ground Fault, Power Status																										
Uninterruptable Power Supply Status																										
Hydrogen Detectors																										
DC Battery System Status																										
Lighting in Shelters Status																										
Tunnel Lighting Status																										
Trench Lighting Status																										
Lighting Inverter Status																										
LV Main and Tie Circuit Breakers																										
Plumbing																										
STANDPIPE Status																										
Standpipe Isolation Valve Status																										
Fire Isolation Valve Status																										
WATER METERING (UTILITY)																										
WATER MANAGEMENT AND IRRIGATION																										
CHILLED WATER SYSTEM (for Tunnel Cooling)																										
HOT WATER SYSTEM (?)																										
DRAINAGE SYSTEM																										
SUMP PUMP Status																										
NATURAL GAS SYSTEM																										
GAS METERING (UTILITY)																										

Facilities MEP SCADA Subsystem																										
Mechanical																										
Escalator Status																										
Elevator Status																										
EMERGENCY STANDBY GENERATOR Status																										
FIRE SUPPRESSION SYSTEM Status																										
CLEAN AGENT ("Clean Gas") SYSTEM Status																										
HEATING, VENTIALTION AND AIR CONDITIONING SYSTEM Status																										
Air Handling Units																										
Fan Coil Units																										
Air Terminal Units																										
EXHAUST SYSTEM																										
EMERGENCY VENTILATION SYSTEM (indoors?)																										
Battery room ventilation Status																										
COMPRESSED AIR SYSTEM																										
CRUCIAL ROOM STATUS, HEAT, HUMIDITY, WATER LEVEL (FLOODING), SIMILAR																										
Electrical																										
Electrical Status, Ground Fault, Power Status																										
HV AND LV POWER DISTIBUTION status																										
Energy and Power Metering																										
HV Circuit Breakers status																										
HV Transformers Status																										
HV Motor Control Centers Status																										
Automatic Transfer Switches																										
LV Main and Tie Circuit Breakers (@ Switchboards and\or Unit Substations)																										
UNINTERRUPTABLE POWER SUPPLY Status																										
Hydrogen Detectors																										
DC BATTERY SYSTEM Status																										
LIGHTING Status																										
Lighting Inverter Status																										
LV Main and Tie Circuit Breakers Status																										
PLUMBING																										
WATER METERING (UTILITY)																										
WATER MANAGEMENT AND IRRIGATION																										
CHILLED WATER SYSTEM																										
HOT WATER SYSTEM																										
DRAINAGE SYSTEM																										
SUMP PUMP																										
NATURAL GAS SYSTEM																										
GAS METERING (UTILITY)																										
Fixed Remote Telemetry SCADA Subsystem																										
Automatic Fare Collection Status																										
Radio Tower aircraft lighting																										
Communications shelter radio surge and lighting supression on signal lines equipment																										
Misc. Equipment Alarms (For equipment with no status indication)																										
TBD																										
1																										

Chapter 28

Communications

HSR 13-06 - EXECUTION VERSION

Revision	Date	Description
0	02 Mar 12	Initial Release, R0

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Acronyms

AC	Alternating Current
ADA	Americans with Disabilities Act
ANSI	American National Standards Institute
ATC	Automatic Train Control
BRS	Broadband Radio System
CAI	Customer Assistance Intercom
CCTV	Closed Circuit Television
CHST	Not Used; use HST for California High-Speed Train
CHSTP	California High-Speed Train Project
CI	Cable Infrastructure
CIC	Communication Interface Cabinet
CIF	Common Intermediate Format
CL-PS	Connection-Less Packet-Switched
DAS	Distributed Antenna System
DC	Direct Current
DOD	Department of Defense
EACS	Electronic Access Control System
EI	Emergency Intercom
EF	Entrance Facility
EIA/TIA	Electronic Industries Association/Telecommunications Industry Association
EMI	Electromagnetic Interference
EMS	Element Management System
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
EVACS	Emergency Voice Alarm Communication System
FAS	Fire Alarm System
GETS	Government Emergency Telecommunications Service
GNTS	Global Positioning System Network Timing System
GSM–R	Global System for Mobile Communications - Railway
GUI	Graphical User Interface
HMI	Human-Machine Interface
HST	High-Speed Train
HVAC	Heating, Ventilation, and Air Conditioning
ID	Intrusion Detection
IDS	Intrusion Detection System

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IIMP	Integrated Information Management Platform
ISO	International Organization for Standardization
LAN	Local Area Network
LOS	Line-of-Sight
MOI	Maintenance of Infrastructure
NFPA	National Fire Protection Association
NMS	Network Management System
NS/EP	National Security and Emergency Preparedness
O&M	Operations and Maintenance
OCC	Operations Control Center
OCS	Overhead Contact System
ORS	Operations Radio System
NCS	National Communications System
PACIS	Public Address and Customer Information Sign System
PIN	Personal Identification Number
PoE	Power over Ethernet
PSTTRS	Public Safety Trench and Tunnel Radio System
QoS	Quality-of-Service
RCC	Regional Control Center
RF	Radio Frequency
RS	Radio System
RSM	Rolling Stock Maintenance
SCADA	Supervisory Control and Data Acquisition
SPT	Sound Power Telephone
TCC	Train Control and Communications
TCCR	Train Control and Communications Room
TIS	Telephone and Intercom System
TPF	Traction Power Facility
TSP	Telecommunications Service Priority
UL	Underwriters Laboratories Inc.
UPS	Uninterruptible Power Supply
VPN	Virtual Private Network
WAN	Wide Area Network
WLAN	Wireless LAN
WPS	Wireless Priority Service

28 Communications

28.1 Scope

The purpose of the Communications Design Criteria is to present the requirements, guidelines, principles, and processes that must be followed to successfully design communications systems for the California High-Speed Train (HST) system. These underlying Design Criteria govern the design of communications systems and shall be applied consistently across the entire system.

Communications systems are used to support the provisioning, safe operation, and cost-effective operations and maintenance of the HST system. The Designer shall design the communications systems using these criteria and guidelines to support the requirements of the project.

This document is organized into the following sections:

- General Design Criteria that applies to all communications systems
  - End-to-End Design Criteria that applies to the design of the Transport Network consisting of the Wide Area Network (WAN), Local Area Networks (LANs), and Radio System (RS).
  - Individual Communications System Design Criteria that applies uniquely to the individual communications system.
- Design Criteria for communications sites, rooms, spaces, and other field equipment.
- Design Criteria for external communications services
  - Telecommunications Services
  - Infotainment Services
  - Backup Virtual Private Network (VPN) connections

Each section (excluding Section 28.5, Communications Physical Support Rooms, Enclosures, Shelters and Equipment, and Section 28.6, External Services) is divided into five subsections of Design Criteria:

- Architecture Design Criteria – High-level Design Criteria focused on system architecture, redundancy, overall system configuration, and management of the system (i.e., the administrative tasks associated with monitoring the performance of a system, fault diagnostics, configuring the system and similar).
- Spare Capacity, Expansion and Obsolescence Design Criteria – Design Criteria focused on spare capacity, expansion, and obsolescence.

- Command and Control Design Criteria – Design Criteria focused on how the systems are controlled locally and remotely.
- Physical, Enclosure and Power Design Criteria – Low-level Design Criteria focused on system components' physical support characteristics, including, cabinets, enclosures, heating, ventilation and air conditioning (HVAC), power, uninterruptible power supply, and similar.
- End-Device Design Criteria – Low-level Design Criteria focused on end-device attributes, placement, and characteristics.

The following is a list of the communications systems that are the topic of these criteria:

- Cable Infrastructure (CI)
- Wide Area Network (WAN)
- Local Area Network (LAN)
- Integrated Information Management Platform (IIMP)
- Global Positioning System (GPS) Network Timing System (GNTS)
- Radio System (RS)
- Fire Alarm System (FAS)
- Telephone and Intercom System (TIS)
- Closed Circuit Television (CCTV) System
- Public Address and Customer Information Sign System (PACIS)
- Intrusion Detection System (IDS)
- Electronic Access Control System (EACS)

Detailed functional and performance requirements of the communications systems are to be provided in separate Communications System Performance Specifications.

28.2 Regulations, Codes, Standards, and Guidelines

Refer to the *General* chapter for requirements pertaining to regulations, codes, and standards.

- Code of Federal Regulations (CFR)
  - Title 47 CFR, Part 90: Private Land Mobile Radio
  - Title 47 CFR, Part 15: Class A
  - Title 49 CFR, Ch. II 220.0: Railroad Communications
  - Title 49 CFR, Part 236 Appendix E: Human-Machine Interface (HMI) Design

- Association of American Railroads (AAR) Standards Manual of Standards and Recommended Practices, Section K
- Americans with Disabilities Act (ADA)
  - 28 CFR Part 35: Title II Technical Assistance Manual
  - 28 CFR Part 36: Title III Standards of Accessible Design
  - 49 CFR Part 37: Transport Services for Individuals with Disabilities
- National Fire Protection Association (NFPA) Codes and Standards
  - NFPA 70: National Electrical Code
  - NFPA 72: National Fire Alarm Code
  - NFPA 130: Standard for Fixed Guideway Transit and Passenger Rail Systems
- American National Standards Institute (ANSI)
  - ANSI –J-STD-607-A: Commercial Building Grounding (Earthing) and Bonding Requirements for Telecommunications
  - ANSI/ICEA S-87-640: Standard for Outside Plant Communications Cable
  - ANSI/ICEA S-80-576: Communications Wire and Cable for Wiring of Premises
  - ANSI/ICEA S-83-596: Standard for Fiber Optic Premises Distribution Cable
  - ANSI/HFES 100: Human Factors Engineering Requirements for Visual Display Terminal (VDT) Work Stations
  - ANSI/IEEE C37.90.2: Standard for Tolerance of Radiated Electromagnetic Frequency Interference (RFI)
  - ANSI/BICSI 002: Data Center Design and Implementation Best Practices
- Institute of Electrical and Electronics Engineers (IEEE) Standards
  - IEEE 802.1: Bridging and Management
  - IEEE 802.3: Ethernet
  - IEEE 802.11: Wireless LANs
  - IEEE 828: Standard for Software Configuration Management Plans
- International Organization for Standardization (ISO) Standards
  - ISO/IEC 12207: Systems and software engineering -- Software life cycle processes
- Electronic Industries Association/Telecommunications Industry Association (EIA/TIA) Standards
  - TIA 603: Land Mobile FM or AM Communications Equipment Measurement and Performance Standards

- EIA-316: Minimum Standards for Portable/Personal Land Mobile Communications FM or PM Equipment
- EIA-310: Cabinets, Racks, Panels, and Associated Equipment
- EIA 472: Generic Specifications for Fiber-optic cable
- EIA/TIA-598: Optical Fiber Cable Color Coding
- TIA-475.0000: Generic Specifications for Fiber Optic Connectors
- TIA/EIA-455: Standard Test Procedures for Optical Fibers, Cables, Transducers, Sensors, Connecting and Terminating Devices, and other Fiber Optic Components.
- TIA-102: Project 25 Digital Wireless Radio Communications
- TIA/EIA 568: Commercial Building Telecommunications Cabling Standards
- TIA/EIA 569: Commercial Building Standard for Telecommunications Pathways and Spaces

• Underwriters Laboratories Inc. (UL) Publications

- UL 6: Rigid Metal Conduit
- UL 44: Thermoset-Insulated Wires and Cables
- UL 50: Standard for Enclosures for Electrical Equipment
- UL 62: Flexible Cords and Cables
- UL 94: Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances
- UL 467: Grounding and Bonding Equipment
- UL 486 A-E: Wire Connectors
- UL 510: Standard for Polyvinyl Chloride, Polyethylene and Rubber Insulating Tape
- UL 514A: Metallic Outlet Boxes
- UL 514B: Conduit, Tubing, and Cable Fittings
- UL 886: Outlet Boxes and Fittings for Use in Hazardous (Classified) Locations
- UL 1581: Reference Standard for Electrical Wires, Cables and Flexible Cords
- UL 1778: Uninterruptible Power Supply Equipment

• Telcordia [Bellcore]

- Network Equipment-Building System (NEBS) Level 3 requirements
- GR-20: Generic Requirement for Optical Fiber and Optical Cables

  - GR-63: NEBS Requirements: Physical Protection
  - GR-771: Generic Requirements for Fiber Optic Splice Closures
- U.S. Department of Defense (USDOD) Standards
  - MIL-STD-1472: Human Engineering
  - MIL-STD-781: Reliability, Test Methods, Plans, and Environments for Engineering, Development, Qualification and Production
  - MIL-STD-810: Department of Defense Test Method Standard for Environmental Engineering Considerations and Laboratory Tests
- National Transportation Communications for ITS Protocol (NTCIP) Standards
- International Union of Railways (UIC) Code / Union Industry of Signaling (UNISIG) Specifications
- European Integrated Radio Enhanced Network (EIRENE) Standards
- MObile radio for RAilway Networks in Europe (MORANE) Standards
- International Telecommunication Union (ITU) Telecommunication Standardization Sector (ITU-T) Standards

28.3 Related Documentation

Related systems disciplines documents interfacing and/or related with the communications system shall be consulted to ensure compliance with required Design Criteria.

- Design Criteria Chapters:
  - General
  - Trackway Clearances
  - Utilities
  - Structures
  - Stations
  - Support Facilities
  - Facility Power and Lighting Systems
  - Building Automation and Management Systems
  - Traction Power Supply System
  - Overhead Contact System and Traction Power Return System

- Grounding and Bonding Requirements
- Automatic Train Control
- Electromagnetic Compatibility and Interference
- Supervisory Control and Data Acquisition Subsystems
- Rolling Stock-Core System Interfaces
- Reliability, Availability, Maintainability and Safety

28.4 Communications Systems

The communications systems listed in Section 28.1 enable the Authority to provide a passenger-friendly, secure, safe, and efficient means of transportation to its ridership. The communications systems consist of field devices, centralized equipment, systems interface, integration and control software, and wired and wireless networks to provide connectivity. The proper design and operation of the communications systems is crucial to passenger and personnel safety and operations and maintenance.

28.4.1 General Communications Systems

The communications systems are individual systems that function independently and in-concert to deliver communications services and functionality to the CHSTP. The following Design Criteria and sections apply to all communications systems unless more specific or stringent criteria are listed in the individual sections.

28.4.1.1 General Communications Systems Architecture

The adherence to open system architecture concepts and non-proprietary standards is required, whenever it is available, to ensure interoperability of products from 2 or more manufacturers.

The CHSTP shall be implemented with an overarching Integration and Information Management Platform (IIMP) to provide a common front-end user interface that allows monitoring and control of various subsystems. This IIMP shall integrate the different types of subsystems (e.g., CCTV, ACS, TIS, SCADA) as well as systems of the same type but implemented using different manufacturer platforms (e.g., different manufacturer video management system software). This level of flexibility is especially required given the large scope and scale of the CHSTP and the phasing of implementation over many years. See Section 28.4.7 for Design Criteria specific to the IIMP.

Standard commercial-off-the-shelf devices shall be used when such equipment and materials meet the functional and performance specifications. Special designs and custom assemblies shall be confined to those devices that require such features to assure compliance with the specifications.

Each communications system shall have self-diagnostics built into the system whereby end-devices, inputs and components can be remotely interrogated to determine their health and operational status and allow fault diagnosis and repair in response to failures.

Electrical-mechanical (dry-contact), direct, or similar triggering interface between stand-alone communications systems (e.g., TIS and CCTV) shall be avoided when permitted by code. Interfaces and integration between communications systems and other systems shall be accomplished via the Integration Logic within the IIMP.

28.4.1.2 General Communications Systems Spare Capacity, Expansion, and Obsolescence

Communication system design shall minimize the effects of early component or subsystem obsolescence caused by advances in technology.

The communications systems shall be designed to facilitate future integration of additional Authority's facilities and right-of-way without interruption of the already operating system when these additions are implemented.

Communication systems, equipment and cabling shall be designed for an operational lifespan as declared in the *General* chapter.

The communications systems shall be designed to accommodate a full-scale deployment along the Authority's entire proposed right-of-way. Nothing in the design shall preclude the Authority from expanding the systems via subsequent, open procurements. The communications systems shall be designed to have a scalable, flexible, open, and non-proprietary architecture.

Over and above the above requirement for accommodating a full-scale deployment along the Authority's entire proposed right-of-way, the communications systems, equipment, infrastructure, support systems, rooms, and enclosures shall be designed and installed to have spare capacity as described in each section.

28.4.1.3 General Communications Systems Command and Control

In general, all users will utilize the IIMP as the front-end application that provides the ability to monitor and control the communications systems. There may be cases where certain system administration tasks (e.g., configuring a device) may require the user to utilize the native system graphical user interface (GUI) to perform the task; however, this should be avoided if possible.

In general, each communications system shall be designed to have multiple levels of command and control by users located at the Operations Control Center (OCC), Regional Control Centers (RCC), stations, facilities, and yards. Each communications system shall be designed to have an application programming interface allowing the

appropriate IIMP (see Section 28.4.7) to interface with the system to provide integration and interface functionality.

28.4.1.4 General Communications Systems Physical, Enclosure and Power

Equipment serving similar functions shall be in the same relative location in equipment cabinets wherever practicable.

Equipment cabinets within communication rooms shall be located so that rack-mounted equipment can be accessed via the front and the back of the equipment cabinet. Equipment mounted within wall-mounted enclosures or cabinets shall be mounted such that front and rear access to the equipment is possible via swing-out equipment rack mounting.

Each equipment cabinet and equipment enclosure shall have a main breaker that can shut off power to equipment in the cabinet or enclosure.

Equipment that is part of different systems and is to be maintained by maintainers with different skill sets should not be located within the same equipment cabinet or equipment enclosure.

Equipment enclosures that are not located within environmentally and particulate-controlled communications equipment rooms shall be NEMA-4 rated. These equipment cabinets and equipment enclosures shall be sealed and lockable and be designed to meet the environmental requirements of the housed equipment.

Equipment cabinets and enclosures shall be as specified in the *Electromagnetic Compatibility and Interference* chapter.

Communications system equipment in tunnel areas shall be located primarily in cross passages.

Equipment cabinet and enclosure doors shall be equipped with lockable handles. Locks shall be keyed alike. Doors shall be removable when unlocked. Electronic lock cylinders and electronic keys that allow access control to cabinets and enclosures shall be designed and included.

Normal diagnostics shall not require major disassembly of the equipment or of any other equipment.

Communications equipment enclosures, housings, conduit pathways and spaces shall not violate the clearances as specified in the *Trackway Clearances* chapter and shall be spatially coordinated with the requirements in the *Tunnels* and *Structures* chapter.

Loads of communications equipment enclosures, housings, conduit pathways and cabling mounted on structures shall not exceed the load limits specified in the *Structures* chapter.

<u>Power and Uninterruptible Power Supply</u>

The communications systems shall be designed to operate using 120 V ac, 1 phase, 60 Hz power sources or other standardized dc power sources.

DC power supplies shall be provided when needed and critical networking, fire, life, safety and radio equipment power supplies shall be designed to be N+1 redundant.

Refer to the *Traction Power Supply System* and *Facility Power and Lighting Systems* chapters for normal, backup and emergency power supply and uninterruptable power supply (UPS) details at buildings, facilities, stations and control centers.

At remote locations including wayside communications interface cabinets, communications shelters at traction power facilities, automatic train control facilities, standalone radio sites, the Designer shall provide uninterruptible power supplies to power communications systems equipment and support equipment for a minimum of 8 hours, after normal and / or backup power is lost.

Communications equipment shall be capable of automatic start-up following a power outage of any length without requiring manual re-initialization.

Communications equipment shall retain full status memory and process recall when operating on power from UPS, generator, battery, or inverter sources.

28.4.1.5 General Communications Systems End-Devices

Exposed cables, connectors, sockets, end-devices, and antennas that are supplied under the contract shall be tamper and vandal proof and aesthetically compatible with the surrounding environment. The installation of such equipment within facility and station buildings shall meet the aesthetic requirements of the respective architects.

Equipment shall, wherever practical, be designed to contain a self-diagnostic capability to permit the remote interrogation of the health and operational status of the unit and facilitate speedy repair after failure.

Onboard antennas shall be roof mounted and shall be positioned to not interfere with other antennas or exceed the current dynamic envelope of the vehicle, fixed equipment envelope and static gauge. The vehicles will operate under a wide variety of electrical operating environments, including under Overhead Contact System (OCS) equipment. Lightning arresters shall be provided for any roof-mounted equipment, including antennas, to suitably protect against lightning strikes and accidental contact with the OCS. Any device near an OCS shall meet the clearance requirements as specified in the *Overhead Contact System and Traction Power Return System* chapter. Individual RS onboard antenna design shall be done in coordination with the other onboard antenna design. A combined antenna package may be suitable if functional and performance requirements are met.

Onboard antennae and radio access points placed near the OCS shall be designed to mitigate, as much as practicable, the effects of near-field OCS interference with the RS.

Communications end device placement shall not violate the clearances as specified in the *Trackwork Clearances* chapter and shall be spatially coordinated with the requirements in the *Tunnels* and *Structures* chapter.

Loads of communications end devices mounted on structures shall not exceed the load limits specified in the *Structures* chapter.

Air gap required by radio or visual communications systems or end devices shall be coordinated with the fixed equipment envelope and the static and dynamic envelopes as specified in the *Trackwork Clearances* chapter. Communications end device locations shall be coordinated with structural and architectural elements. See *Stations, Support Facilities* and *Structures* chapters.

Mounting of end devices and conduits on concrete shall not interfere with rebar.

28.4.1.6 Communications Systems and Supervisory Control and Data Acquisition Subsystems

Please see the *Supervisory Control and Data Acquisition Subsystems* chapter for Design Criteria for SCADA subsystems.

The communications systems that interface to the SCADA subsystems are limited to the transmission and display of SCADA subsystems status and control messages via any standard, approved data interfaces as required via the WAN or LAN. While it will be the responsibility of the WAN and LAN to meet the connectivity, security, latency, reliability metrics demanded by the various disciplines requiring this service, the WAN and LAN are a data delivery service only.

SCADA devices attached to the WAN and/or LAN networks may include wayside and station seismic, wind speed, and other hazard-monitoring devices, facilities control and alarm reporting, traction power facilities, SCADA, and other sensors, alarms and devices needing remote monitoring and control. The WAN and LANs are responsible for delivering SCADA data messages to the Master Terminal Units (MTUs).

28.4.2 End-to-End Design Criteria – the Transport Network

The foundation of the communications systems is the Transport Network, which consists of interconnected wired and wireless networks that securely and reliably move data between devices, applications, and equipment. The performance and availability of the Transport Network has direct correlation to the performance and availability of other systems that rely on the Transport Network to move data. For example, the performance (i.e., the response times, quality of video, up-time) of a CCTV system as seen by an end-user depends not only on the performance of the CCTV equipment (e.g.,

cameras, servers, video displays) but also on the performance of the Transport Network that transports the video streams between CCTV equipment.

The systems that make up the Transport Network are the WAN, LAN, and RS. This chapter specifically discusses these 3 systems as 1 in order to capture the importance and Design Criteria of interface between the separate communications systems. The term "node" is used here to signify a single or group of interconnected equipment that together provide the required network functions at a particular location.

The WAN shall provide data connectivity to the entire HST system via core and edge rings. The WAN core nodes should exist at passenger stations, Rolling Stock Maintenance (RSM) and Maintenance of Infrastructure (MOI) facilities, and the RCC and OCC. The WAN edge nodes should exist at traction power facilities, Automatic Train Control (ATC) equipment houses, stand-alone radio sites, wayside communication interface cabinets, and tunnel ventilation facilities at tunnel portal sites and tunnel ventilation facilities at tunnel ventilation shafts.

The LANs shall provide short-range networking (e.g., in buildings or between nearby buildings) between local devices and equipment. The LANs shall exist at passenger stations, control centers, and facilities. LANs in a smaller configuration exist co-located with the WAN edge nodes to provide local end-device connectivity. Local end-devices shall connect to the Transport Network via LANs. The LAN shall support redundant, physically distributed connections to the WAN, to provide the backhaul connectivity described above. The LANs shall provide network connectivity between local devices/equipment and aggregate traffic from local devices that are destined for remote locations prior to delivering the traffic to the WAN, thus reducing the number of interfaces required on WAN nodes.

The WAN nodes (core and edge) shall be designed to allow transit traffic (i.e., traffic passing through the WAN node but not destined to any local devices) to be offloaded from modules or equipment responsible for routing packets. The WAN nodes shall also be designed to support traffic engineering to allow control of network paths.

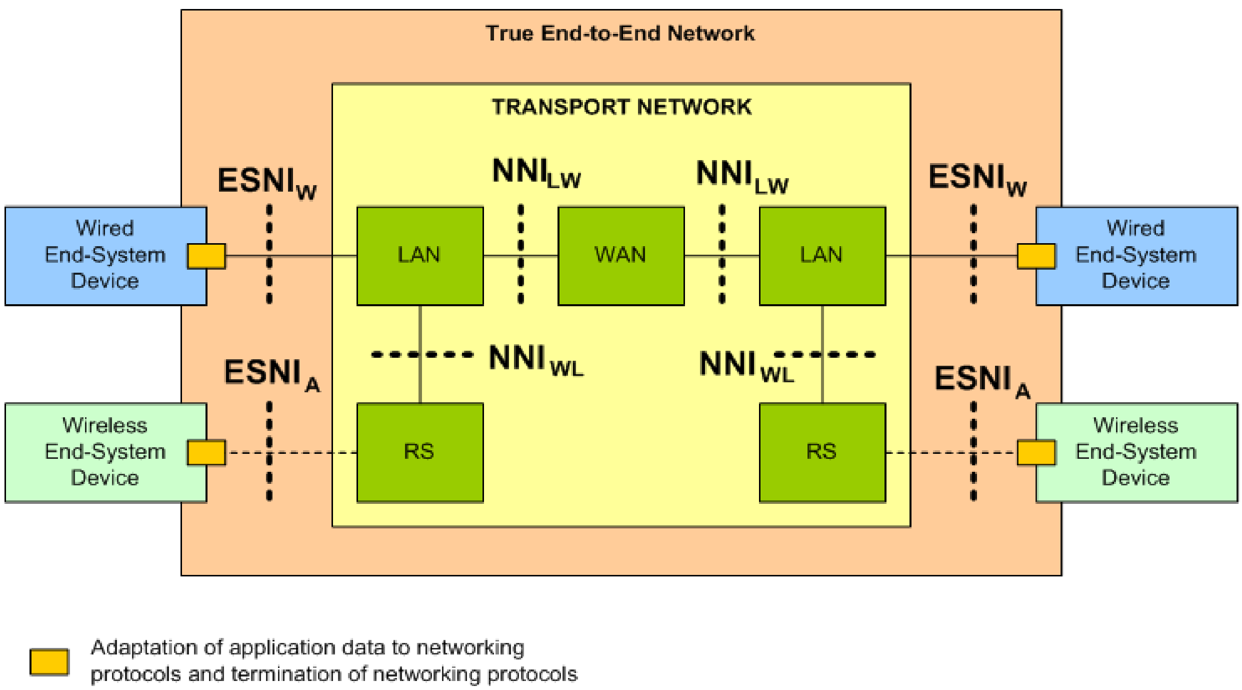
Two RS subsystems are part of the Transport Network. These separate radio subsystems provide wireless connectivity to mobile systems, equipment, and Authority users. These RSs are the following:

- **Operations Radio System (ORS)** – voice and low-bandwidth data RS for wireless communications between onboard equipment, mobile and portable users and fixed users and systems (if a radio-based train control system is used, the ORS shall carry safety-critical train control data, see the *Automatic Train Control* chapter)
- **Broadband Radio System (BRS)** – high-bandwidth RS for wireless communications between onboard high-bandwidth systems and fixed systems while trains are in motion, including at 250 miles per hour (mph).

28.4.2.1 Transport Network Architecture

The Transport Network, as shown in Figure 28-1, is a partition of the actual "end-to-end" network. The end-to-end network consists of the network level functions present in the end-system devices as well as the networking equipment. The Transport Network is the partition containing the networking equipment. The Transport Network partition itself consists of multiple partitions as shown in Figure 28-1: the WAN, LAN, and RS. The Transport Network shall provide network services to wired and wireless end-system devices. Wired end-system devices shall have a physical network connection to a LAN. Wireless end-system devices shall have a physical network connection over-the-air to the RS. The RS shall be connected to the WAN or LAN via a wired connection, and the LANs in different facilities shall be interconnected via the WAN.

Figure 28-1: Transport Network Partitions



The network interfaces between each of the network partitions are shown in Figure 28-1 and listed below:

- End-System to Network Interface (Wired) – $ESNI_W$
- End-System to Network Interface (Air) – $ESNI_A$
- Network to Network Interface (RS to LAN) – NNI_{WL}
- Network to Network Interface (LAN to WAN) – NNI_{LW}

The end-to-end network shall provide the transfer of data between the application processes running in the end-systems. The end-to-end network includes the network level functions present in the end-system devices as well as the networking equipment.

The end-system devices shall implement protocols that perform the functions throughout all 7 layers of the Open Systems Interconnection model (i.e., perform the application level processes associated with the top 2 layers, end-to-end logical connectivity functions associated with the Session and Transport layers, as well as the networking functions associated with the lower 3 layers).

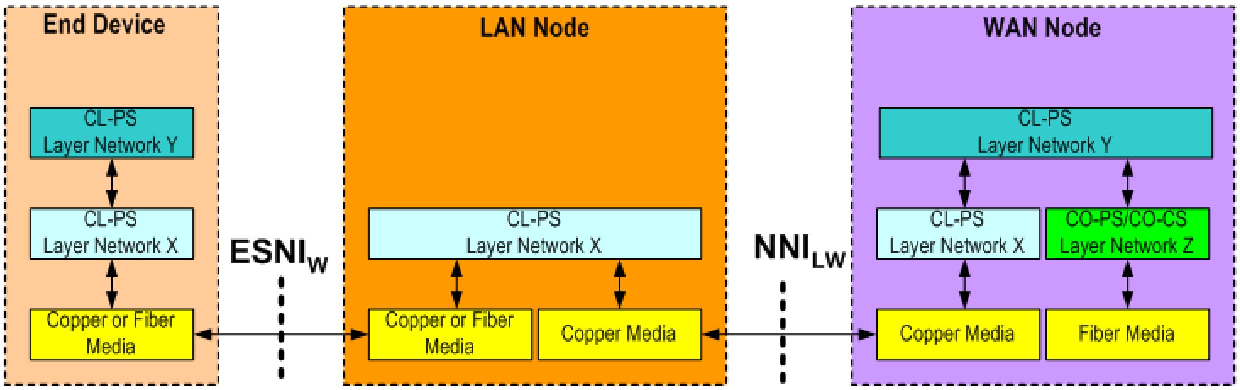
The network equipment used to interconnect the end-system devices shall perform various functions associated with the lower 3 layers. End-system devices, which could be specified by non-communications disciplines and possibly procured under different contracts, also contain "network functions." Therefore, the designers shall consider these end-devices as part of the end-to-end network and conduct design such that they are interoperable with the network equipment to ensure end-to-end delivery of the application data.

Network design shall minimize the different types of networking protocols and technologies while meeting the requirements for data transport across the network for applications. The Designer shall therefore design for a common network interface (or small set of network interfaces) to be defined and used by systems to connect to the networks. The Designer shall reduce the different types of equipment and technologies supported by the network to allow the Authority to maintain less spare equipment in storage, reduce the number of technologies and equipment types that maintenance personnel are required to be trained in, and, in general, permit a simpler network design.

It shall be the responsibility of the Designer to determine the best network protocol stacks to implement each of the above interfaces. Provided below are design guidelines and criteria that the Designer shall utilize when conducting network design and selecting the network protocols. The Designer shall note that different partitions of the Transport Network may be designed and installed by different designers and coordination will be required to ensure that the above interfaces are fully defined (i.e., protocol stack specified) to ensure interoperability and end-to-end functionality (based on the procurement plan).

Figure 28-2 illustrates the layer networks supported across the $ESNI_W$ and the NNI_{LW} interfaces. Since protocols are not specified herein, the layer networks are referred to as Layer Network X, Layer Network Y, and Layer Network Z. The Designer shall note that Layer Network Z does not cross those interfaces that have been defined between different network partitions and remains solely within the WAN partition (i.e., is used solely between WAN nodes).

Figure 28-2: Layer Networks across the ESNI$_W$ and NNI$_{LW}$ Interfaces



Any layer network may be categorized as 1 of 3 distinct classes of networks;

- Connection-Less Packet-Switched (CL-PS)
- Connection-Oriented Packet-Switched (CO-PS)
- Connection-Oriented Circuit-Switched (CO-CS) networks

Layer Network Y, which is the end-to-end layer network beginning and ending on end-system devices, shall be a CL-PS layer network. A CL-PS network allows for any-to-any communications without having to configure a full-mesh of connections in the network and therefore is a more flexible solution for end-to-end communications. Layer Network Y shall support a scalable address format and routing mechanism suitable for WANs with hundreds of nodes and tens of thousands of end-points.

The address format supported by Layer Network Y shall support hierarchical addressing that signifies a location within a network topology. Such an address format will allow for address summarization, which allows the network to scale to support many end-points.

The routing mechanism supported by Layer Network Y shall support optimal routing across the network and not require packets to be broadcast out to all links before a route is learned.

Layer Network X, which is the layer network responsible for transporting data locally within a station or facility, shall be a CL-PS layer network as well. However, Layer Network X, being a local network, does not need to support the same level of scalability as described for Layer Network Y, and therefore a simpler, less expensive networking technology may be used to support Layer Network X (e.g., Ethernet bridging/switching).

Layer Network Z is a layer network that resides totally within the WAN partition. Unlike Layer Networks X and Y, Layer Network Z does not cross the ESNI$_W$ or NNI$_{LW}$

interfaces. Layer Network Z shall be either a CO-PS or CO-CS layer network. The functions provided by Layer Network Z shall be:

- Traffic Engineering
- Off-load of pass-through traffic at a WAN node from the Layer Y processor
- Deterministic network recovery mechanism to recover against failures to WAN links or equipment
- Disassociate the physical fiber topology from the logical Layer Y topology (e.g., logical connections in Layer Z can be configured to provide Layer Y a logical mesh, while the underlying physical fiber topology may be a ring)

Types of Data Traveling on the Transport Network

The primary function of the Transport Network is to move data between the application processes running in the end-system devices. The data being transmitted and/or received by the application process may be in the form of messages, files, or real-time streams.

The Designer shall design a network that meets the performance requirements for the transport of messages, files, and real-time streams (both non-interactive and interactive) end-to-end across the interfaces and partitions defined in Figure 28-2.

Transport Network End-to-End Performance Objectives

Different partitions of the network will likely be designed and built by different designers, portions of the end-to-end performance objectives shall be allocated amongst the various partitions to ensure compliance of partitions as well as end-to-end compliance.

28.4.2.2 Transport Network Spare Capacity, Expansion and Obsolescence

There are no specific criteria. See Section 28.4.1.2 and the individual chapters for WAN, LAN, and RS.

28.4.2.3 Transport Network Command and Control

There are no specific criteria. See Section 28.4.1.3 and the individual chapters for WAN, LAN, and RS.

28.4.2.4 Transport Network Physical, Enclosure and Power

There are no specific criteria. See Section 28.4.1.4 and the individual chapters for WAN, LAN, and RS.

28.4.2.5 Transport Network End-Devices

There are no specific criteria. See Section 28.4.1.5 and the individual chapters for WAN, LAN, and RS.

28.4.3 Wide Area Network

The WAN consists of the hardware and software required to switch, manage, process, control, monitor, and deliver data traffic between field locations and central control facilities via the fiber-optic CI. The WAN shall deliver system data via the CI between any points on the network in a secure and reliable fashion. Data traffic includes voice, video, as well as any control, alarm, and status messages plus Network Management System (NMS) data used to support operations. Data traffic includes communications systems traffic and other disciplines’ data traffic.

It shall be the responsibility of the WAN to meet the connectivity, security, latency, and reliability metrics requested by the various disciplines requiring data transfer service.

The WAN includes but is not necessarily limited to the following equipment/modules and subsystems:

- Optical network node equipment/modules
- Network switching equipment/modules
- Management System

28.4.3.1 Wide Area Network Architecture

The WAN shall be designed to utilize fiber-optic links to connect the WAN nodes such that each WAN node has geographically diverse links connecting it to at least 2 other non-co-located WAN nodes so that no single point failure of the WAN equipment or CI can reduce the capability of the WAN to provide service with adequate QoS. The WAN nodes shall utilize standard, non-proprietary protocols to transport data, automatically detect network faults, and provide automatic network recovery.

The network connectivity provided by the WAN shall be designed to be flexible to allow communications between any 2 WAN nodes and therefore provide a means to allow any control facility to take over system-wide operations in the event of a failure of the other(s).

WAN equipment shall be designed to support a configuration with multiple control modules. To support high availability, 2 control modules (built-in or modular) shall be furnished and installed for network equipment. These 2 control modules shall be provisioned to operate in a hot-standby capacity, such that if 1 control module fails the other shall take over without any loss of service. For modular control modules, the equipment shall operate such that if 1 control module is unplugged (e.g., for replacement) and replaced with another control module, the entire process shall take place with no loss of service.

WAN equipment shall be capable of supporting a configuration with multiple switching fabrics (i.e., multiple redundant forwarding backplanes).

The WAN shall be designed such that traffic is capable of being routed around any single equipment failure or cable failure.

The WAN shall be necessarily designed in segments across multiple contracts. Subsequent additions to the WAN shall be designed to be compatible and interoperable with the previous WAN segments.

Due to the wide area of coverage provided by the WAN, it is critical that the WAN equipment along with the WAN Element and Network Management Systems (EMS and NMS) provide the fault, configuration, administration, performance, and security functions as specified in ITU-T Recommendation M.3400, using standard protocols.

The Designer shall design a WAN NMS that will be used as a maintenance engineering tool for configuring, controlling, and monitoring the WAN. WAN NMS shall be used primarily for system configuration, detailed equipment diagnostic and fault-finding purposes, and shall include necessary equipment such as hardware and software.

The NMS and WAN EMS shall include health-status monitoring of the systems to a level of detail that typically includes fiber-optic transmit/receive multiplexers, repeaters, channel units, control modules, switching fabrics, and local and remote power supplies. The WAN NMS shall include equipment necessary for communications system monitoring and control.

28.4.3.2 Wide Area Network Spare Capacity, Expansion, and Obsolescence

The initial segments of the WAN shall be designed to support the traffic capacity of the eventual proposed, full build out of the CHSTP system, plus enough spare capacity to be able to reroute traffic around a single failure with no measurable degradation in QoS to be defined in the performance specifications, plus, over and above this capacity, additional spare capacity to support a 50 percent traffic growth. As new segments come on-line there shall not be any need to increase the capacity of links or equipment installed in previous WAN segments.

28.4.3.3 Wide Area Network Command and Control

No specific end-device Design Criteria. See Section 28.4.1.3.

28.4.3.4 Wide Area Network Physical, Enclosure, and Power

WAN equipment shall support a configuration with multiple power supply modules. To support high availability, 2 power supplies (built-in or modular) shall be furnished and installed for network equipment. These 2 power supply modules shall be provisioned to operate in a hot-standby hot-swappable capacity, such that if 1 power supply fails, the other shall take over without any loss of service. For modular power supplies, the equipment shall operate such that if 1 power supply is unplugged (e.g., for replacement) and replaced with another power supply, the entire process shall take place with no loss of service.

28.4.3.5 Wide Area Network End-Devices

There is no specific end-device Design Criteria. See Section 28.4.1.5.

28.4.4 Local Area Networks

The LAN is the communications network within a passenger station area, facility, traction power facility, stand-alone radio site, and ATC equipment house to which devices and systems interface to provide connectivity to the local control point, central head-end equipment, and the WAN.

28.4.4.1 Local Area Network Architecture

Critical workstations and servers shall have 2 connections to the LAN and each connection shall be terminated on different LAN equipment.

The LAN shall support at least 2 connections to the WAN. Upon failure of 1 connection to the WAN, the LAN and the WAN shall be capable of automatically rerouting traffic onto the other connection using standard protocols. The Designer shall ensure that the 2 connections are continually used with load balancing rather than only 1 connection actively carrying traffic at all times.

The LAN shall be designed such that traffic is capable of being routed around any single equipment failure or cable failure.

LAN equipment shall support a configuration with multiple control modules. To support high availability, 2 control modules (built-in or modular) shall be furnished and installed. These 2 control modules shall be provisioned to operate in a hot-standby capacity, such that if 1 control module fails the other shall take over without any loss of service. For modular control modules, the equipment shall operate such that if 1 control module is unplugged (e.g., for replacement) and replaced with another control module, the entire process shall take place with no loss of service.

The LAN EMS shall include health status monitoring of the systems, to a level of detail that typically includes switches, routers, power supplies and similar. The LAN EMS shall include equipment necessary for LAN monitoring and control.

28.4.4.2 Local Area Network Spare Capacity, Expansion and Obsolescence

The LANs shall be designed with 25 percent spare capacity, processing and connectivity to accommodate future increased usage, end-devices, and expansion.

LANs shall be designed with spare capacity to support the full build out of the system, and over and above this capacity, an additional 25 percent spare capacity.

28.4.4.3 Local Area Network Command and Control

There is no specific end-device Design Criteria. See Section 28.4.1.3.

28.4.4.4 Local Area Network Physical, Enclosure and Power

LAN equipment shall support a configuration with multiple power-supply modules. To support high availability, 2 power supplies (built-in or modular) shall be furnished and installed. These 2 power supply modules shall be provisioned to operate in a hot-standby hot-swappable capacity, such that if 1 power supply fails the other shall take over without any loss of service. For modular power supplies, the equipment shall operate such that if 1 power supply is unplugged (e.g., for replacement) and replaced with another power supply, the entire process shall take place with no loss of service.

28.4.4.5 Local Area Network End-Devices

No specific end-device Design Criteria. See Section 28.4.1.5.

28.4.4.6 Wireless LAN

The Wireless LAN (WLAN) is a wireless physical layer extension to the LAN. The WLAN shall be installed at indoor manned office locations at stations, facilities and control centers to provide secure WLAN access to Authority personnel via portable electronics (e.g., tablets and laptops). The WLAN shall also be deployed outdoors at the Yards and Terminal Stations for purposes of transmitting stored video, train health, and other stock data to maintenance facilities during out-of-service operations. This high-bandwidth WLAN shall be used to transmit large video, audio and telemetry data files while trains are stationary.

<u>Wireless LAN Architecture</u>

WLAN shall enable secure wireless access to the local LAN via wireless access points.

Coverage shall be provided for Authority personnel computing devices at the following:

- Back office areas, paid and unpaid areas, and platforms at stations
- Back office areas at facilities and control centers

Coverage shall be provided for offload of onboard data where trains are stored and maintained at the following:

- Terminal Station yard areas
- RSM Yards
- MOI Yards

The data rate and capacity of this system shall be designed such that video and other data shall be downloadable within the maintenance window established by the operations and maintenance group for the maximum number of trains possibly present within the range of the access point(s).

Security mechanisms shall be provided to prevent unauthorized users access to the WLAN.

In the event of a security breach via the WLAN, access to critical systems shall not be possible.

The WLAN may be provided via unlicensed spectrum. Frequency coordination and interference studies shall be done to minimize impacts to the WLAN.

The WLAN shall interface with the LANs and WAN to support system-wide communications.

Radio frequency (RF) coverage simulations shall be performed to verify and validate wireless system infrastructure and wireless system parameters.

The Designer shall perform a capacity analysis study to determine the amount of bandwidth frequencies/channels required to support the WLAN wireless traffic requirements.

Radio system design shall ensure that restoration of lost data frames be accomplished by re-transmission of unacknowledged (lost) frames.

Wireless system propagation and antenna design shall be designed primarily to employ line-of-sight (LOS) radio links where possible.

Consideration shall be given to the characteristics of the onboard radio antennae. Wayside antennae shall be designed and deployed to maintain optimal and consistent radio signal strength regardless of the changes in orientation of the rolling stock antennae.

WLAN wireless nodes shall be designed that the failure of 1 node or other incident resulting in the loss of RF signal from that node shall be compensated by the 2 other adjacent access points.

WLAN connection must be seamlessly transferred as a mobile radio moves between different coverage areas within the same building, site, or location.

<u>Wireless Local Area Network Spare Capacity, Expansion, and Obsolescence</u>

The WLAN shall be designed with sufficient capacity to support the full build out of the system, plus, over and above this capacity, an additional 25 percent spare capacity, processing, and connectivity to accommodate future increased usage, end-devices and expansion.

<u>Wireless Local Area Network Command and Control</u>

There are no specific criteria. See Section 28.4.1.3.

Wireless LAN Physical Enclosure and Power

There are no specific criteria. See Section 28.4.1.4.

Wireless LAN End-Devices

There are no specific criteria. See Section 28.4.1.5.

28.4.5 Radio System

The RS consists of separate radio subsystems that provide wireless connectivity to mobile systems, equipment, and users. These RSs are:

- **Operations Radio System (ORS)** – voice and low-bandwidth data RS for wireless communications between onboard equipment, mobile and portable users and fixed users and systems (if a radio-based train control system is used, the ORS shall carry safety-critical train control data, see the *Automatic Train Control* chapter).
- **Broadband Radio System (BRS)** – high-bandwidth RS for wireless communications between onboard high-bandwidth systems and fixed systems while trains are traveling at speeds up to 250 mph.
- **Public Safety Trench and Tunnel Radio System (PSTTRS)** – extends coverage of existing public safety/first responder RS into the CHSTP trenches and tunnels to allow such first responders to access their respective RS as they normally do in their existing coverage areas.

The ORS and BRS shall include tunnel and trench wireless systems to extend respective RF coverage into tunnels and trenches as needed.

28.4.5.1 Operations Radio System

The ORS will carry voice and low-bandwidth data for wireless communications between onboard equipment, mobile and portable users and fixed users and systems. While a European Train Control System (ETCS)/GSM-R is desired, the RS deployed may be a standard land mobile radio, GSM-R, or similar system, depending on requirements and RF spectrum availability. If a radio-based train control system is used, the ORS shall carry safety-critical train control data and shall have critical interfaces with the Train Control System, see the *Automatic Train Control* chapter. The ORS shall be designed with adequate bandwidth for voice and data including train control, alarm and event notification, onboard public address and passenger information signs, and other onboard communications subsystems.

The ATC component of the European Rail Traffic Management System (ERTMS) and the ETCS Level 2 defines continuous communications between the train and the radio block center for movement authority while not necessarily requiring wayside signals. The movement authority is communicated directly from a radio block center to the onboard unit using GSM-R. In-track balises are used to transmit only "fixed messages" such as

location, gradient, speed limit, etc. A continuous stream of data from the wayside is transmitted to the onboard computer, which, via the Human-Machine Interface (HMI), informs the train engineer of the movement authorities and line-specific data on the route ahead, allowing the train to run at maximum or optimal speed while maintaining a safe braking distance.

GSM-R, the data bearer for ETCS Level 2, is a multi-function radio solution that supports critical train control data, train to wayside voice communication, multiple voice channels for railroad personnel, and passenger information. GSM-R includes various special railroad requested services such as emergency, group or broadcast calls, functional or location dependent addressing, call prioritizing, paging, telemetry, and other data in a single, integrated radio solution.

<u>Operations Radio System Architecture</u>

ORS shall be designed to utilize a radio tower infrastructure positioned at existing traction power facilities, signal instrument houses, stations, tunnel portal sites, and stand-alone radio sites—each spaced to give a nominal tower spacing of 2.5 miles. To achieve functional and performance requirements, the Designer shall look to antenna optimization, placement on existing commercial tower sites or buildings, and similar and, as a last resort, additional radio towers and supporting shelters and sites.

The ORS shall be implemented so that no single point failure of the ORS equipment can reduce the capability of the ORS to provide continuous connectivity with adequate QoS defined in the functional and performance specifications.

RF coverage simulations shall be performed by the Designer to verify and validate wireless system infrastructure and wireless system parameters (including continuous coverage along the Authority's entire right-of-way), including validating continued coverage despite a single site failure. ORS shall be designed in such a manner that the failure of 1 node (downing of an antenna or other incident resulting in the loss of RF signal from that node) shall be compensated by the 2 other adjacent stations.

The ORS System shall be provided via a licensed RF spectrum. This RF spectrum shall be for the exclusive use of the Authority.

The Designer shall perform a capacity analysis study to determine the number of frequencies/channels required to support the wireless traffic requirements.

Both uplink and downlink channels shall be designed to support train speeds of up to 250 mph and shall be designed to provide rapid handover from wayside communication equipment without system impacts due to loss of data.

Signal strength value required to support system QoS and bit-error rate metrics shall be maintained during handoff by overlapping radio coverage between wireless communication points along the alignment.

Wireless system design shall ensure that wayside handoffs are “make before break.” This means that handoffs to a new base station shall provide that the connection shall not be dropped from the previous node until a new connection with the target base station is established.

Wireless system design shall ensure that restoration of lost data be accomplished by re-transmission of unacknowledged or lost data.

Wireless system propagation and antenna design shall be designed primarily to employ LOS radio links where possible. Antenna design, selection and placement shall place the main lobe of any directional antenna with the LOS of the alignment as much as feasible. The beamwidth of such antenna (up to 60 degrees) shall be selected based on the location of the next closest wayside wireless node antenna consistent with providing for LOS conditions under local curves of the track alignment.

Consideration shall be given to the characteristics of the onboard radio antenna at intermediate points between 2 wayside wireless transceivers. Wayside antennae shall be designed and deployed in such a manner to maintain optimal and consistent radio signal strength regardless of the momentary changes in orientation of the rolling stock antennae.

The ORS shall support operational and emergency voice communications and low-speed data communications.

ORS radios (portable and mobile type) for transit operations, maintenance, and police personnel shall include but not be limited to the following: voice and data logging, retrieval, and archiving systems.

The ORS (if GSM-R) shall be designed with interfaces and control such that when outside the RF coverage range of the ORS, mobiles and portables shall use commercial cellular GSM for non-critical voice and data.

The RS shall be designed, furnished, installed, and maintained in accordance with the Association of American Railroads Manual of Standards and Recommended Practices, Section K.

Operations Radio System Spare Capacity, Expansion, and Obsolescence

The ORS shall be designed to accommodate future packet-switched network infrastructure capabilities.

The ORS shall be designed to support the traffic capacity of the eventual proposed, full build out of the CHSTP system and, over and above this capacity, an additional 25 percent spare capacity, processing and connectivity to accommodate future increased users, usage, end-devices, and expansion.

Operations Radio System Command and Control

The HMI for ATC and voice radio shall comply with the relevant requirements of 49 CFR Part 236 Appendix E and shall be developed with ergonomic considerations for visibility of radio displayed indications and radio functions that require Locomotive Engineer interaction with the display.

Operations Radio System Physical Enclosure and Power

There are no specific criteria. See Section 28.4.1.4.

Operations Radio System End-Devices

In the event that the Contractor proposes an ERTMS Level 2 system, the air gap interfaces shall generally meet the requirements of UNISIG Subset-037; EuroRadio Functional Interface Specification, UNISIG Subset-046; Radio In-fill Form Fit and Function Interface Specification, UNISIG Subset-047; Trackside-Trainborne FIS, UNISIG Subset-092-1; ERTMS EuroRadio Conformance Requirements, and UNISIG Subset-092-2; ERTMS EuroRadio Test cases Safety Layer, UNISIG Subset-026; System Requirements Specification, UNISIG Subset-034; Functional Interface Specification for the Train Interface, UNISIG Subset-108; Interoperability consolidated requirements, UNISIG Subset-048; Trainborne Form Fit Functional Interface Specification for Radio In-Fill, and A11T6001 12 MORANE Radio Transmission Form Fit and Function Interface Specification for Euradio.

The design for the position of all antennas on the rolling stock shall be such that reliable communication is assured at the extremes of the track geometry and route geography that the rolling stock traverses. The movement and dynamic and static behavior of the rolling stock shall be taken into account.

The position of antennas on or about the vehicle roof and underneath the body of the train shall take into account antennas and other equipment and structural elements that might affect radio and transponder detection and communication.

28.4.5.2 Operations Radio System at Trench and Tunnel Locations

The ORS shall be extended into trenches and tunnels to provide seamless radio functionality for the trench and tunnel segments on the alignment. The Designer shall extend radio coverage of the ORS into tunnels and trenches where the at-grade ORS cannot provide coverage.

The system may include exposed, at-grade antennas for off-air interface, channelization equipment and RF-on-fiber transmission subsystem feeding the underground Bidirectional Amplifiers, which in turn will feed the underground distributed antenna system (DAS). If a GSM-R system is deployed, underground DAS feed may be fed by a base transceiver station feed from the WAN. Bi-directional amplifiers located in the tunnel shall amplify, repeat, and distribute off-air ORS gathered from at-grade antennas.

These signals shall be distributed using radiating coaxial, and use of power feeder cable, RF splitters, point-source antennae, cable taps, cross-band couplers, and other devices as necessary.

Operations Radio System at Trench and Tunnel Locations Architecture

The ORS at trench and tunnel locations shall be designed to work efficiently in all trench and tunnel types, configurations, constructions, and combinations present.

Prior to the start of design, the tunnels and trenches shall be analyzed for determination of the proper level of signal amplification required to conform to the performance requirements.

The design shall consist of 2 redundant distributed antenna feeds at the opposite tunnel portals, with both sites available as backup to the other in the event of an equipment failure or antenna coaxial break. The ORS at trench and tunnel locations shall be implemented so that no single-point failure of the equipment can reduce the capability of the ORS at trench and tunnel locations to provide continuous connectivity with adequate QoS to be defined in the functional and performance specifications.

The system shall be designed to reduce, as much as practicable, the effects of near-field OCS interference with the RS served by the DAS at all frequencies of operations. Any device near OCS shall meet the clearance requirements as specified in the *Overhead Contact System and Traction Power Return System* chapter.

Multiple DASs will need to be co-located in a trench, tunnel, or bore to provide multiple radio services in differing bands. Each system shall be designed in a manner that the bands of operation of 1 radio service shall not interfere with or degrade the performance of the ORS traffic.

Filtering and other mitigations shall be employed to reduce the risk of performance degrading interference by all co-located DASs.

Operations Radio System at Trench and Tunnel Locations Spare Capacity, Expansion and Obsolescence

There are no specific criteria. See Section 28.4.1.2 and 28.4.5.1.

Operations Radio System at Trench and Tunnel Locations Command and Control

There are no specific criteria. See Section 28.4.1.3 and 28.4.5.1.

Operations Radio System at Trench and Tunnel Locations Physical Enclosure and Power

There are no specific criteria. See Section 28.4.1.4 and 28.4.5.1

Operations Radio System at Trench and Tunnel Locations End-Devices

Leaky coaxial antenna radiating systems shall be free from co-locations with any metal objects that could perturb or attenuate the antenna RF radiating field per manufacturers' mounting instructions.

Leaky coaxial antenna radiating elements shall be mounted and powered such that adequate signal level can be transmitted to ORS antennas whether inside our outside the train, whichever case is worse and performance requirements can be met.

28.4.5.3 Broadband Radio System

The BRS is a high-bandwidth wireless system for wireless communications between onboard high-bandwidth systems and fixed systems while trains are traveling at speeds up to 250 mph. The primary data traffic transmitted via the BRS is CCTV video.

Broadband Radio System Architecture

Broadband wireless equipment shall be provided on the train to transmit and receive data wirelessly, with BRS access points located along the wayside, in tunnels, at stations, and yards to provide the required coverage.

The BRS shall be designed primarily to support the required bandwidth necessary to transfer real-time video data from/to the train in primary support of the onboard CCTV system.

The BRS shall interface with the LANs and WAN to support system-wide communications.

The BRS may be provided via unlicensed spectrum. Frequency coordination and interference studies shall be done to minimize interference and blocking impacts to the BRS.

The BRS may be designed to optionally utilize an antenna-tower infrastructure positioned at existing traction power facilities, signal instrument houses, stations, tunnel portal sites and stand-alone radio sites, each spaced to give an ultimate tower spacing of approximately 2.5 miles or, based on spectrum used, BRS access points may need to be mounted on wayside poles to create "short-path" access point infrastructure.

RF coverage simulations shall be performed to verify and validate wireless system infrastructure and wireless system parameters.

The Designer shall perform a capacity analysis to determine the amount of spectrum required to support the BRS wireless traffic requirements.

Both uplink and downlink channels shall be designed to support train speeds of up to 250 mph and shall be designed to provide rapid handover from wayside communication equipment without significant system impacts due loss of data.

Signal strength value required to support system QoS and bit error rate metrics shall be maintained during handoff by overlapping radio coverage between wireless communication points along the alignment.

Wireless system design shall ensure that wayside handoffs are ‘make before break” This means that handoffs to a new wireless node shall provide that the connection shall not be dropped from the previous node until a new connection with the target node is established.

Wireless system design shall ensure that restoration of lost data be accomplished by re-transmission of unacknowledged (lost) data.

Wireless system propagation and antenna design shall primarily be designed to employ LOS radio links where possible. Antenna design, selection and placement shall place the main lobe of any directional antenna with the LOS of the alignment as much as feasible, the beamwidth of such antenna (up to 60 degrees) shall be selected based on the location of the next closest wayside wireless node antenna consistent with providing for LOS conditions under local curves of the track alignment.

Consideration shall be given to the characteristics of the onboard radio antenna at intermediate points between 2 wayside wireless transceivers. Wayside antennae shall be designed and deployed in such a manner to maintain optimal and consistent radio signal strength regardless of the momentary changes in orientation of the rolling stock antennae.

BRS wayside wireless nodes shall be designed in such a manner that the failure of 1 node, downing of an antenna, or other incident resulting in the loss of RF signal from that node shall be compensated by the 2 other adjacent stations.

Broadband Radio System Spare Capacity, Expansion and Obsolescence

The BRS and shall be designed to support the traffic capacity of the eventual proposed, full build out of the CHSTP system and, over and above this capacity, an additional 25 percent spare capacity, processing and connectivity to accommodate future increased users, throughput, usage, end-devices, and expansion.

Broadband Radio System Command and Control

There are no specific criteria. See Section 28.4.1.3.

Broadband Radio System Physical Enclosure and Power

There are no specific criteria. See Section 28.4.1.4.

Broadband Radio System End-Devices

There are no specific criteria. See Section 28.4.1.5.

28.4.5.4 Broadband Radio System at Trench and Tunnel Locations

The BRS at trench and tunnel locations shall be designed and integrated with the BRS for seamless functionality for the trench and tunnel segments on the alignment. The BRS at trench and tunnel locations shall extend two-way coverage of the BRS into tunnels and trenches where the at-grade BRS cannot provide coverage.

Depending on whether the BRS at trench and tunnel locations utilizes a close-proximity propagation scheme (e.g., access points are mounted on short poles very close to the Authority's right-of-way), the same close-proximity propagation scheme may be suitable for coverage within trenches and tunnels.

Broadband Radio System at Trench and Tunnel Locations Architecture

Within trenches and tunnels, the BRS may simply be able to reuse the above-ground infrastructure scheme underground if the access points are mounted in very close proximity to the trains.

The BRS at trench and tunnel locations shall be designed to work efficiently in all trench and tunnel types, configurations, constructions, and combinations present within the CHSTP.

Prior to the start of design, the tunnels and trenches shall be analyzed for determination of the proper level of signal amplification required to conform to the performance requirements.

BRS at trench and tunnel locations shall be designed to reduce as much as practicable, the effects of near-field OCS interference with the RS served by the DAS at all frequencies of operations. Any device near OCS shall meet the clearance requirements as specified in the *Overhead Contact System and Traction Power Return System* chapter.

Multiple DASs will need to be co-located in a trench, tunnel, or bore to provide multiple radio services in differing bands. Each system shall be designed in a manner that the bands of operation of 1 radio service shall not interfere with or degrade the performance of the ORS traffic, which is high-priority.

Filtering and other mitigations shall be employed to reduce the risk of performance degrading interference by both DASs.

Broadband Radio System at Trench and Tunnel Locations Spare Capacity, Expansion and Obsolescence

There are no specific criteria. See Section 28.4.1.2 and 28.4.5.3.

Broadband Radio System at Trench and Tunnel Locations Command and Control

There are no specific criteria. See Section 28.4.1.3 and 28.4.5.3.

Broadband Radio System at Trench and Tunnel Locations Physical Enclosure and Power

There are no specific criteria. See Section 28.4.1.4 and 28.4.5.3..

Broadband Radio System at Trench and Tunnel Locations End-Devices

The BRS at trench and tunnel locations' radiating system shall be installed at a sufficient distance from metal objects to avoid perturbation or attenuation of the antenna RF radiating field per manufacturers' mounting instructions.

Leaky coaxial antenna radiating elements shall be mounted and powered such that adequate signal level can be transmitted to BRS antennas whether inside our outside the train, whichever case is worse and performance requirements can be met.

28.4.5.5 Public Safety Trench and Tunnel Radio System

The Public Safety Trench and Tunnel Radio System (PSTTRS) shall extend coverage of existing public safety/first responder radio systems into the CHSTP trenches and tunnels to allow such first responders to access their respective radio systems as they normally do in their existing coverage areas. Such public safety/first responder radio systems are anticipated to fall into 1 of the following categories:

- VHF Public Safety
- UHF Public Safety
- 700 MHz for Public Safety Spectrum Trust and California 700 MHz Regional Planning Committees 5 and 6
- 700 MHz Public Safety Broadband
- Other state, local and municipal RS as appropriate.

Design for the PSTTRS shall provide coverage and signal strength and Delivered Audio Quality levels consistent with the needs of the public safety community in areas of the alignment where such systems are deployed for in-tunnel repeaters. An assessment of the needs and capabilities of the local emergency response agencies will be made by the Fire/Life Safety and Security Committee for each trench or tunnel location where PSTTRS is to be deployed.

The design shall adhere to applicable Federal Communications Commission and National Public Safety Planning Administration Committee Region 6 (Northern California) and Region 5 (Southern California) planning regulations for 700 MHz Public.

Public Safety Trench and Tunnel Radio System Architecture

The PSTTRS design shall consist of 2 redundant distributed antenna feeds from the opposite tunnel portals, with both sites available as backup to the other in the event of an equipment failure or antenna coaxial break. The PSTTRS shall be implemented so

that no single-point failure of the PSTTRS equipment can reduce the capability of the PSTTRS to provide continuous connectivity with adequate QoS to be defined in the functional and performance specifications.

The PSTTRS shall be designed to work efficiently in all trench and tunnel types, configurations, constructions, and combinations present.

Prior to the start of design, the tunnels and trenches shall be analyzed for determination of the proper level of signal amplification required to conform to the performance requirements.

System shall be designed to reduce as much as practicable, the effects of near-field OCS interference with the RS served by the DAS at all frequencies of operations. Any device near OCS shall meet the clearance requirements as specified in the *Overhead Contact System and Traction Power Return System* chapter.

Multiple DASs will need to be co-located in a trench, tunnel, or bore to provide multiple radio services in differing bands, each system shall be designed in manner that the bands of operation of 1 radio service shall not interfere with or degrade the performance of the ORS traffic, which is high-priority.

Filtering and other mitigations shall be employed to reduce the risk of performance degrading interference by multiple DASs.

Public Safety Trench and Tunnel Wireless System Spare Capacity, Expansion and Obsolescence

The system shall be expandable to accommodate 25 percent future public safety radio channels and capacity as they come in service.

Public Safety Trench and Tunnel Wireless System Command and Control

There are no specific criteria. See Section 28.4.1.3.

Public Safety Trench and Tunnel Wireless System Physical Enclosure and Power

There are no specific criteria. See Section 28.4.1.4.

Public Safety Trench and Tunnel Wireless System End-Devices

The PSTTRS leaky coaxial radiating system shall be installed at a sufficient distance from metal objects to avoid perturbation or attenuation of the antenna RF radiating field per manufacturers' mounting instructions.

Leaky coaxial antenna radiating elements shall be mounted and powered such that adequate signal level can be transmitted to transceivers inside the train and performance requirements can be met.

28.4.5.6 Radio Interoperability with External Agencies and First Responders

These requirements are developed based on pending requirements from Operations (including Authority relationship with statewide public safety radio systems).

28.4.6 Cable Infrastructure

The CI is the copper and fiber-optic cable, and related equipment supporting the communications systems.

The Designer shall properly design a structured CI to support a broad range of communications systems and applications. Structured cabling allows diverse applications to be served by the same cabling system. In a structured cabling system, separate facilities are not required for voice and data systems. The communications rooms and closets shall be designed to accommodate the communications services required by the systems including expansion margins.

A combination of fiber and twisted-pair copper cables shall be used to support communications requirements.

The Designer shall employ equipment and fiber-optic cable in uses for which it is specified, where fiber will avoid the possibility of electromagnetic interference, and for cable runs that exceed the distance limitations of copper cable.

Along the wayside, fiber-optic and copper cabling shall be installed in cable troughs adjacent to the rail and in conduit feeding wayside sites. Fiber-optic cable shall be installed on both sides of the track within a protected cable trough to provide redundancy via physical diversity, so that no single point failure can result in a loss of WAN service. Fiber-optic cable will be provided along the Authority's entire right-of-way in both surface, aerial, trench and tunnel segments. Crosstrack connectivity shall be provided at each station and wayside facility requiring access to near and far cable trough per Section 28.5.6.

The primary communications system that interfaces with and uses the fiber-optic cable provided along the Authority's right-of-way is the WAN; however, some communications systems or other discipline systems may require dedicated fiber strands for their exclusive use.

The premises horizontal cabling maximum distance shall be 295 feet, independent of media type (UTP, coax, fiber). This allows 32 feet for patch cords and equipment cables. If a telecom outlet is used, the maximum distance will be reduced in accordance to TIA/EIA-568-B.1.

28.4.6.1 Cable Infrastructure Architecture

Premises backbone cabling shall be installed in a ring topology.

Horizontal cabling shall be installed in a star topology. Each cable shall be a home run without splices. Application-specific electrical components (such as impedance matching devices) shall not be installed as part of the horizontal cabling. These components, if necessary shall be added externally to the outlet.

The Designer shall comply with applicable structured cabling standards published by ISO/IEC and ANSI TIA/EIA related to designing, manufacturing, installing, and field testing CI consisting of unshielded and screened balanced twisted pair and fiber-optic cables and connectors.

Cables shall be designed and installed to be immune to electromagnetic interference (EMI) levels that are expected in high-speed rail environments per the *Electromagnetic Compatibility and Interference* chapter.

Cable and conduit located at seismic movement joints between structures and seismic fault crossings shall be designed with appropriate provisions to accommodate the expected long term and short term/large, single-event earth deflection standards.

28.4.6.2 Cable Infrastructure Spare Capacity, Expansion and Obsolescence

The Designer shall design for and implement the latest category twisted pair cabling available for twisted pair cabling, as appropriate.

Non-conduit cable pathways, raceways and troughs shall have at least 25 percent additional space for future needs. 25 percent additional empty conduit shall be installed to accommodate additional cabling.

The fiber-optic cable routed in the wayside trenches supporting the WAN shall be installed with additional 100 percent spare capacity.

When practical, 25 percent spare capacity for the addition of future equipment shall be included within equipment cabinets and enclosures.

25 percent spare equipment cabinets shall be added to the number of equipment cabinets per equipment room. Equipment rooms shall be designed to support the needs of the eventual proposed, full build out of the CHSTP system, to accommodate the normal and spare amount of equipment cabinets, spare conduit penetrations and 25 percent additional wall mounted equipment.

28.4.6.3 Cable Infrastructure Command and Control

Not Applicable

28.4.6.4 Cable Infrastructure Physical, Enclosure and Power

All cables shall be tamper-proof. Cables shall not be run unprotected in exposed areas. When cables are run in exposed areas the cables shall be located within steel conduit for cable protection.

In concealed spaces at stations and other indoor facilities, cables shall be housed in Electrical Metal Conduits (EMT). Intermediate Metal Conduit (IMC) shall be used for cable runs in exposed passenger areas but not in a concealed space.

28.4.6.5 Cable Infrastructure End-Devices

Cables within cabinets and enclosures shall be neatly arranged using cable management accessories providing adequate clear space for equipment maintenance. Cabinets shall be tamper proof.

Cable terminations shall have cable tags identifying the cable number, the number of copper pairs or fiber strands in the cable, the distant end (where the cable goes) and the route that it takes.

Interior materials shall meet the requirement of non-flammability and smoke emission resistance such that no toxic gases are produced in the event of fire. Communications cables, including those used for the power supply, installed in underground and enclosed locations and tunnels shall be fire resistant, low smoke, non-toxic and halogen-free.

Cables used within systems used to aid in the evacuation of a station during a fire condition shall be able to maintain circuit integrity under fire conditions. The cable shall be rated to withstand the worst case heat levels that the cable would be exposed to for 3-hours given the various emergency evacuation scenarios (e.g., station fire, explosion). The BS6387 Fire Performance Standard specifies 3 category levels currently; Cat A (3-hours at 1202 °F), Cat B (3-hours at 1382 °F), and Cat C (3-hours at 1742 °F).

Dimensions, weights, sizes and quantities of cables run within cable troughs shall be coordinated with the cable trough dimensions as described in the *Structures* chapter.

Lateral cable runs entering or exiting or crossing the cable troughs shall not cross over longitudinal cable runs. Lateral cable runs shall pass below longitudinal cables.

Cable spool lengths shall be selected to avoid the need for splicing at an intermediate point between the manholes along the Authority's right-of-way. Splices should occur within entrance facility rooms at sites or at wayside sites.

If splicing is required at-grade, at an intermediate location, the splices shall be stored within a cabinet above ground within 10-feet of the cable trough on the wayside. 10-feet of cable slack shall be provided and stored in loop within the cabinet.

If splicing is required at an aerial section, at an intermediate location, splices may be conducted within a fiber-optic splice closure mounted in the void area or a cabinet mounted above the void area (the latter is preferred).

If splicing is required at an intermediate location, at a tunnel or trench segment, the splices shall be stored within a cabinet wall mounted above the cable trough. 10-feet of cable slack shall be provided and stored in loop within the cabinet.

Fiber-optic cable service loops of at least 50-feet long shall be installed every 500 feet within all sections of cable trough. The service loops shall be stored on frames mounted to the side wall of the cable trough adjacent to the cable. Service loops shall be installed as to not obstruct 30-foot track-to-trough punch-outs at aerial segments.

Fiber-optic cable installed in cable trough shall be armored.

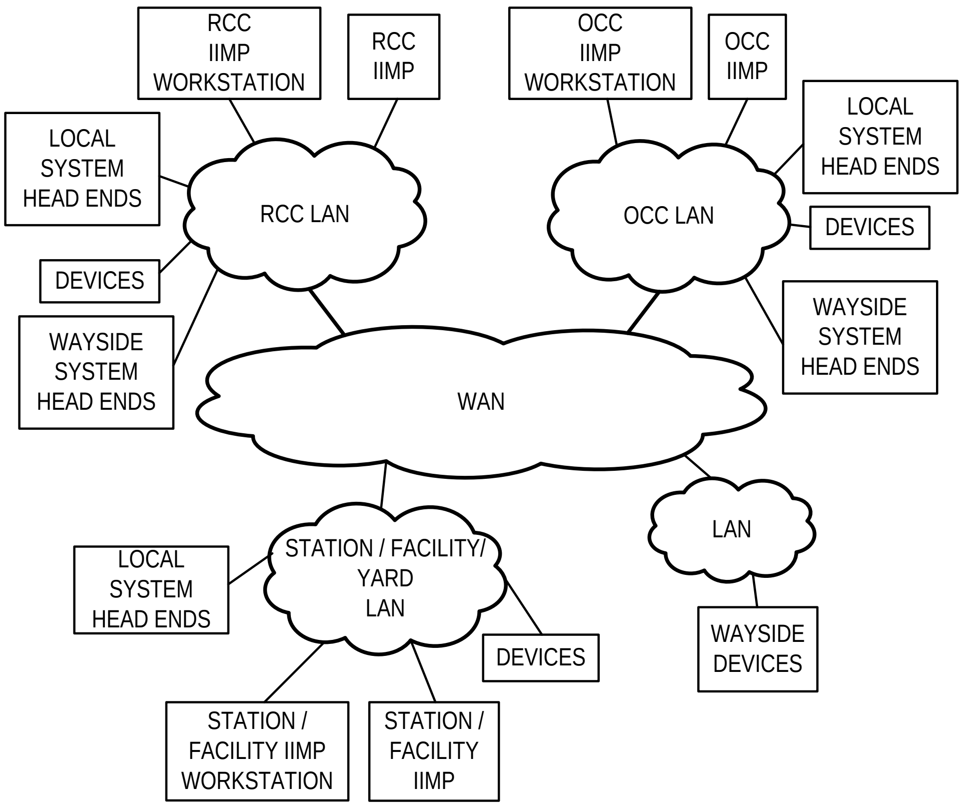
28.4.7 Integrated Information Management Platform

Crucial to integrated operations and maintenance is the IIMP, which shall be designed and optimized to integrate and leverage information from multiple stand-alone communications systems and other devices and systems for streamlined and coherent operation, monitoring and control. IIMPs shall be installed at locations where human control and monitoring and/or system interface will be necessary: at OCCs and RCCs, stations, facilities, and yards.

IIMPs shall exist in multiple locations throughout the alignment and based on their location shall have a different scope of integration and control. IIMPs at the OCC and RCC shall provide integration, interface, and command and control for subtending OCC and RCC systems, wayside systems, and the local IIMPs throughout the alignment. Local IIMPs at stations and facilities shall provide integration, interface, and command and control only for subtending station and facilities systems. The local IIMPs shall pass data to the IIMPs at the OCC and RCC. Local IIMPs may be installed at unmanned facilities such as tunnel ventilation facilities as necessary. At unmanned facilities, these IIMPs will have appropriate workstation functionality.

Each type of IIMP shall support 3 basic functions: interfaces to subtending systems, logic to allow information from 1 system to cause specific actions by other systems, and the HMI or GUI allowing operators to control and monitor each of the subtending systems. IIMPs shall gather and present necessary data to automatically or manually allow the operator, dispatcher, security officer, station manager or maintenance manager to control, monitor and diagnose systems. Status reporting, information storage and retrieval, alarm processing, incident and operation reports shall be provided based on command and control assignments. The IIMPs deployed for the CHSTP shall have connectivity within the system as shown in Figure 28-3.

Figure 28-3: Integrated Information Management Platforms and Workstations



Each IIMP shall support an interface with each of the subtending systems (e.g., Electronic Access Control, Intrusion Detection) that allows the IIMP to communicate with the subtending systems to monitor and control those systems. The IIMP shall interface with the application programming interface of the subtending system in order to communicate, manipulate, and control the subtending systems via the device driver software within the IIMPs.

IIMPs shall be designed to integrate the following systems:

- Communications Systems
- Communications Systems' NMS
- Communications Systems' EMS
- SCADA Subsystems
- Business Systems including Automatic Fare Collection
- External Systems

The integration logic is the software processing of the IIMP, which shall contain the logic required to cause actions in 1 system based upon information in another system (e.g., electronic access control alarm causes video to be streamed to operator workstation).

With this higher level integration platform, each installed communications or other system is required to support only a single interface thereby reducing the complexity of the architecture and making it easier to scale the architecture over time.

The IIMP shall also include the following components:

- Workstations
- HMIs (for audible input for TIS, radio and PACIS system input and similar)
- Videowall display system
- Printers and peripherals

28.4.7.1 Integrated Information Management Platform Architecture

IIMPs shall be designed to perform the system interface functions of the subtending systems based on the systems' requirements. Raw data streams shall be routed as efficiently as possible. The local IIMPs shall be designed to perform interface and integration without the need for transmitting raw, high-bandwidth data streams between remote systems and the OCC- and RCC-located IIMPs.

Local IIMPs shall be developed to operate in a stand-alone function continuing to interface and integrate subtending systems even when WAN connectivity to the central OCC or RCC IIMPs is lost.

28.4.7.2 Integrated Information Management Platform Spare Capacity, Expansion and Obsolescence

Additional interfaces may need to be added to modify existing ones or add new integration functions in the future. With the IIMP concept, only 1 new interface would need to be added if a new system is added: the interface between the new system and the IIMP. Additional logic shall be added to the IIMP to add new integration functions without needing to add new interfaces.

Over and above the projected, full-build capacity, the IIMP shall be designed to accommodate 25 percent additional subtending systems, 25 percent additional integration and interface functionality and 25 percent additional workstations.

28.4.7.3 Integrated Information Management Platform Command and Control

Control workstations at stations, yards, and facilities that interface with the OCC and RCC IIMPs shall be designed to also support manufacturers' stand-alone software command and control GUI to permit local control of local communications systems in the case that connectivity to the OCC and RCC IIMP is lost.

IIMPs shall be designed to integrate control and monitoring for subtending NMSs and EMSs.

The HMI shall be consistent between all similar IIMPs to reduce training.

28.4.7.4 Integrated Information Management Platform Physical, Enclosure and Power

There are no specific criteria. See Section 28.4.1.4.

28.4.7.5 Integrated Information Management Platform End-Device

There are no specific criteria. See Section 28.4.1.5.

28.4.8 Global Positioning System Network Timing System

The GNTS shall be used to synchronize the clocks of communications systems, network equipment, stand-alone digital clocks, devices, and on-train equipment such that time is measured and recorded uniformly and consistently throughout the system. The GNTS receiver shall generate the timing signal required to synchronize systems.

In addition to digital clocks and employee computers, the GNTS shall synchronize clocks in other communication systems that rely on timing functions. These systems include:

- Closed Circuit Television (CCTV) System
- Intrusion Detection (ID) System
- Electronic access control System (EACS)
- Fire Alarm System (FAS)
- Public Address and Customer Information Sign System (PACIS)
- SCADA subsystems
- Radio System (RS)
- WAN and LANs
- On-Board Systems
- Operations and Maintenance (O&M) Systems

28.4.8.1 Global Positioning System Network Timing System Architecture

The GNTS shall be based on the time data transmitted by the GPS satellite system with backup oscillators. GPS inputs and backup oscillators will exist at the OCC and RCCs.

The GNTS shall be designed to automatically fail-over during failure of the active time source.

The GNTS shall be designed to synchronize clocks even in the event that the GPS signal is lost.

Failure of the clock system shall not contribute to the failure of any communications or other systems.

In the event that a master clock is unable to transmit a time signal to systems, these time-based systems and stand-alone digital clocks shall operate on their own internal clock.

User groups inside and outside of CHSTP will rely on the timing provided by GNTS for various operational, investigational, and maintenance purposes. Given that the communication systems above shall be synchronized to a common time source, this will permit the correlation of time-coded events in 1 system to time-coded events in another. For example, security user groups may easily correlate an intrusion alarm to CCTV video of the perpetrator, as these systems are synchronized.

The system shall include a performance management and monitoring system, which shall be integrated into the IIMP.

28.4.8.2 Global Positioning System Network Timing System Spare Capacity, Expansion and Obsolescence

The system shall be designed to support the eventual proposed, full build out of the CHSTP system and over and above this capacity, additionally include 25 percent spare capacity and capability to expand number of synchronized and synchronizing devices.

28.4.8.3 Global Positioning System Network Timing System Command and Control

There are no specific criteria. See Section 28.4.1.3.

28.4.8.4 Global Positioning System Network Timing System Physical, Enclosure and Power

Wall clocks shall be powered by UPS. If Ethernet protocol is used by the LANs, wall clocks shall be powered by Power-over-Ethernet.

28.4.8.5 Global Positioning System Network Timing System End-Devices

Wall clocks shall be digital, with 7-segment or similar display to be specified in the functional and performance specifications. In public areas, hour-minute clocks shall be wall mounted near the passenger service agent booth in stations. In back office areas, hour-minute-second clocks shall be wall mounted in each regularly staffed room. Hallways shall have hour-minute-second clocks mounted at 1 per 250 feet of linear hallway. Hallway clocks shall be mounted such that the readable face is perpendicular to the wall.

Each station shall have a clock designed to the aesthetics of the station and shall be driven by the GNTS. See the *Stations* chapter for details on placement of public clocks

28.4.9 Fire Alarm System

The FAS shall be designed to perform the following functions:

- To monitor the station areas, control centers, facilities and ancillary areas including spaces located within tunnels.
- Initiate alarms (both visible and audible notifications) and activate the fire suppression systems.
- Alert the monitoring and response organizations to the incident.
- Emergency Voice Alarm Communication System (EVACS) to provide pre-recorded and manual voice messaging to building occupants.

28.4.9.1 Fire Alarm System Architecture

A designated street entrance to each station, facility and building shall be provided with an alarm annunciator panel indicating the fire alarm zones and alarm status, per code. FASs shall be addressable and integrated into the building management systems (ventilation, elevators, etc.) and EACS (unlock doors).

The FAS shall comply with the latest versions of the National Fire Alarm codes (NFPA 72) and standards regarding the application, design, installation, location, performance, testing, inspection, and maintenance of FASs and their components. The FAS shall include alarm initiating devices (detection), alarm notification appliances (horns, only in areas where PA elements are not present, and strobes), fire alarm control panels, auxiliary control panels, integrated annunciator panels, and other components to provide a complete system.

The FAS shall be designed per NFPA 72, which permits the transmission of evacuation announcements via compliant mass notification systems (e.g., the Public Address/Customer Information Sign System (PACIS)) permitting a more integrated system where the fire alarm notifications will be transmitted via the PACIS system. To be compliant with the code the cables and loudspeakers of the PA system shall need to comply with UL requirements.

28.4.9.2 Fire Alarm System Spare Capacity, Expansion and Obsolescence

The FAS shall be designed to support the eventual proposed, full build out of the CHSTP system and over and above this capacity, accommodate 25 percent additional fire initiating devices and 25 percent additional fire notification appliances.

28.4.9.3 Fire Alarm System Command and Control

There are no specific criteria. See Section 28.4.1.3.

28.4.9.4 Fire Alarm System Physical, Enclosure and Power

There are no specific criteria. See Section 28.4.1.4.

28.4.9.5 Fire Alarm System End-Devices

Under NFPA 72, the voice notification system (PACIS) shall pass intelligibility tests by either objective or subjective testing. For objective testing, the system shall score a 0.5 or

better reading on the speech transmission index for public address (PA) systems (STI-PA). The Designer shall perform the objective tests to ensure the system complies with the intelligibility requirements of NFPA 72.

28.4.10 Public Address and Customer Information Sign System

The PACIS system shall be designed to give clear, accurate, synchronized, and timely, audible, and visual information to customers and personnel in the station areas, back-office areas, and yards. The PACIS shall serve as the notification element in routine operations and in emergency situations. The PACIS shall be designed to meet ADA requirements; voice announcements shall have an equivalent visual announcement.

The PA subsystem shall utilize a distributed speaker system in each location. The PA subsystem shall utilize signal processing techniques, ambient noise monitoring, and a physical layout designed to ensure audio broadcasts will produce clear, intelligible speech within the area of coverage.

The Customer Information Sign subsystem shall include 2 types of dynamic message visual displays placed strategically throughout stations. Customer Information Displays (CIDs) shall be low-resolution, limited-color, high-visibility Light-Emitting Diode (LED) or similar format. Customer Information Monitors shall be large-format, high-color, high-resolution Liquid-Crystal Display (LCD) or similar format. CID signs shall be used to display customer-oriented textual information including train arrival and delay information delivered by the PACIS headend using data from the ATC system. The CIM signs shall be placed at locations on platforms and mezzanines and generally above passenger service agent booths to provide scheduling and information textually and graphically to passengers.

28.4.10.1 Public Address and Customer Information Sign System Architecture

The PACIS shall be designed to meet the NFPA requirements for an EVACS. Please see Section 28.4.9. The EVACS system will automatically halt normal PACIS system announcements to deliver emergency announcements during emergency situations.

The PACIS shall provide a processing to display/announce messages in a prioritized manner and be capable of automatically overriding current messages/announcements when an emergency or higher priority message shall be broadcast.

The PACIS shall be designed to operate in a zoned manner to allow live and pre-recorded announcements (both audible and visual) to be directed to individual zones, as well as "All-Call" general broadcast announcements.

The PA subsystem shall utilize automatic volume control in stations to automatically compensate for a high wind or high background (crowd, traffic, train) noise environment.

28.4.10.2 Public Address and Customer Information Sign System Spare Capacity, Expansion and Obsolescence

The PACIS shall be designed to support the eventual proposed, full build out of the CHSTP system and, over and above this capacity, accommodate 25 percent more speakers, CIDs, CIMs and 25 percent more message storage.

28.4.10.3 Public Address and Customer Information Sign System Command and Control

Local (at station or facility) and central (OCC, RCC) control shall be provided for each PACIS system.

28.4.10.4 Public Address and Customer Information Sign System Physical, Enclosure and Power

PACIS equipment shall be enclosed in vandal and environmental proof enclosures and may require heating depending on placement.

28.4.10.5 Public Address and Customer Information Sign System End-Devices

<u>Public Address Subsystem Audio Coverage</u>

The PA subsystem shall be designed to provide high speech intelligibility, even when operating in a reverberant and raised ambient noise environment. The system shall be designed and tested to meet the intelligibility requirements in NFPA 72 for an EVACS.

The PA subsystem shall be designed such that sound projects from 1 direction only. The Designer shall not locate speakers in the ceiling and walls in the same area. The Designer shall not locate speakers on walls directed towards each other.

The spacing of speakers shall assure no dead spots or sound pressure level (SPL) variance of more than ±2 dB SPL in the listening zone to be defined in the performance specifications.

The placement of speakers shall allow coverage at the station platform levels, public concourse areas (both paid and non-paid areas), passage walkways, non-public back-office spaces at stations, and parking areas.

The placement of speakers shall allow coverage throughout work areas, including but not limited to security offices, maintenance, communications, mechanical, and electrical rooms, hallways, and restrooms within the control centers and maintenance facilities.

Configuration of loudspeaker zones will vary according to the architectural design of each station and building.

At outdoor locations, the speaker type and placement shall minimize the sound spill of amplified messages into adjacent residential neighborhoods.

Customer Information Signs Visual Coverage

Customer Information Signs shall be provided at station platforms and concourse areas.

Customer information displays on platforms shall be located precisely along the platform and spaced such that each sign is co-located with a train car entrance. One double-sided sign shall be allocated per train car door, at the same location at each train car door when train is stops at a station. Along with arrival, delay and general information, CIDs will display reserved seat information to allow passengers to queue at their appropriate train car.

Customer information displays and monitors within the concourse area shall be located to provide coverage to persons in waiting areas and near ticket sales offices. The provided coverage shall allow a person sitting in any seat within the waiting areas to have a clear view of a CID or CIM screen and the text displayed is legible according to standards NEMA TS4:2005 and EN 12966-1:2005.

The number of displays required per platform depends on various factors including, length of platform, size of characters to be displayed, viewing angles, and height of sign.

CIDs and CIMs shall be located and operate in compliance with ADA requirements.

Audio message announcements from the PA subsystem within a PA subsystem zone shall be displayed as scrolling text messages on the CIDs and/or CIMs located in that zone. The audio and text messages shall be coordinated so that playback to the public occurs at the same time. It shall also be possible to transmit audio and text messages independent of each other.

CIDs and CIMs shall display the time-of-day, synchronized to the GNTS.

28.4.11 Telephone and Intercom System

The TIS shall provide wired voice communication functions for personnel, Authority police personnel, Contract Police and Security personnel, 3rd-party emergency responders and passengers. The system shall include several subsystems for specific user groups and applications. Various types of telephone and/or intercom devices shall be deployed at locations along the Authority's right-of-way, public areas of the passenger station, and in selected ancillary rooms associated with the passenger stations and utility buildings.

28.4.11.1 Telephone Subsystem

The telephone subsystem shall include the following subsystems:

- Administrative Telephones shall provide fixed voice communications between employees to conduct daily operations. Administrative Telephones shall be located

at each workspace, in communications rooms, electrical and mechanical rooms, ticket offices, security offices, conference rooms, and similar.

- Emergency Telephones are adjacent to the motor-operated power disconnects. Emergency Telephones will be used by staff to contact the traction electrification power coordinator to report emergencies and coordinate OCS power shut off.
- Sound Powered Telephones (SPT) System is a stand-alone communications system that does not rely on network connectivity or a power source. SPT shall use electro-mechanical transducers that convert voice into an electrical signal for communication, without use of any external power sources and shall be used as backup in the event of network or radio failures. SPTs shall be located in trenches and tunnels and used by 3rd-party first responders and other personnel under emergency circumstances.
- Public Pay Telephones are installed in the station areas for the benefit of the passengers. The telephones will be provided and installed by the local telephone company. The Designer shall provide the power, spacing, conduit and cabling to interface public pay telephones to the Public Switched Telephone Network demarcation point.

Telephone System Architecture

Voice communications carried by the telephone systems shall be recorded and time-stamped.

Telephone System Spare Capacity, Expansion and Obsolescence

The telephone system shall be designed to support the traffic capacity of the eventual proposed, full build out of the CHSTP system and over and above that, to accommodate 25 percent more telephones, throughput and calls.

Telephone System Command and Control

There are no specific criteria. See Section 28.4.1.3.

Telephone System Physical, Enclosure and Power

Telephone hardware shall be robust, vandal resistant, and designed to withstand and function in the operating environment.

Telephone System End-Devices

SPTs shall be terminated above ground at the emergency command posts at both ends of trenches and tunnels.

An administrative telephone allowing communication to the OCC and RCC, wayside equipment enclosures, other TPF, and the control room of the concerned power utility

grid substation shall be provided at each prefabricated 25 kV switchgear room and each wayside power control cubicle.

28.4.11.2 Intercom Subsystem

The Intercom Subsystem shall include the following:

- Customer Assistance Intercoms (CAIs) shall be installed for passengers to report emergencies and obtain general travel information. CAIs shall have 2 buttons for these 2 different functions.
- Emergency Intercoms (EIs) shall be installed for passengers to report emergencies and shall have a single button to perform this function.
- Station Intercoms shall allow the station attendant to communicate with passengers at fare collection equipment, fare-barrier equipment or through protective glass.

Intercom System Architecture

Voice communications carried by the intercom systems shall be recorded and time-stamped.

Intercom System Spare Capacity, Expansion and Obsolescence

The Intercom system shall be designed to support the traffic capacity of the eventual proposed, full build out of the CHSTP system and over and above that, to accommodate 25 percent more intercoms, throughput and calls.

Intercom System Command and Control

There are no specific criteria. See Section 28.4.1.3.

Intercom System Physical, Enclosure and Power

Intercom hardware shall be robust, vandal resistant, and designed to withstand and function in the operating environment.

Intercom System End-Devices

CAI and EI shall be placed platform and mezzanine locations and coordinated with CCTV camera viewing fields.

28.4.12 Closed Circuit Television System

The CCTV system shall be designed to monitor critical locations along the Authority's right-of-way and in facilities and stations.

The CCTV system is an essential component to providing safety and security to customers and Authority personnel. The CCTV system shall be designed to allow the Authority and/or law enforcement authorities to deter and prevent crimes and attacks,

identify perpetrators and provide a video record useful for any legal proceedings that may follow. Information gathered by the CCTV system will be used to manage assets and alert and dispatch security forces.

The CCTV system shall provide video to Authority users at each station and facility and remotely at the OCC, RCCs, and Terminal Control Facilities. The CCTV system shall be flexible to allow any camera within the system to be viewed by a user at any IIMP depending on the privileges of the user currently logged into the system at the viewing device. Typically, users at stations will only need to view live or recorded video captured by cameras that are local to the station, while users located at the OCC and RCCs shall be able to view live or recorded video captured by cameras that are local as well as remote. When viewing live video captured by local cameras or recorded video stored locally, the video streams shall be transmitted via the LAN only. When viewing live video captured by remote cameras or recorded video stored remotely, the video streams shall be transmitted via the WAN as well as the LANs.

28.4.12.1 Closed Circuit Television System Architecture

Video from cameras except those located onboard trains shall be continuously recorded and stored at the nearest video storage location (i.e., station, maintenance facility, control center) and storage shall be designed to store video for a minimum of 90 days (see Section 28.2.12.2 for spare capacity requirements). This includes wayside cameras and cameras located at smaller facilities including traction power facilities, signal equipment houses and stand-alone radio sites.

The CCTV system shall be designed to NTCIP 1208 Standards.

Video captured by the cameras shall be transmitted to local storage. For cameras at the wayside, video will be stored at the nearest video storage location. Video will be selectively transmitted back to OCC and RCCs based on exception (e.g., alarm triggers the transmission of live video, or the operator manually selects a camera for viewing).

28.4.12.2 Closed Circuit Television System Spare Capacity, Expansion and Obsolescence

The CCTV system shall be designed to support the eventual proposed, full build-out of the CHSTP system and, over and above that, an additional 25 percent more capacity to accommodate more cameras, storage and processing.

28.4.12.3 Closed Circuit Television System Command and Control

The CCTV system shall be designed to the specific chain of custody demands as specified in The *Systems Safety and Security* Chapter.

28.4.12.4 Closed Circuit Television System Physical, Enclosure and Power

CCTV cameras shall be enclosed in vandal and environmental proof enclosures and may require heating depending on placement.

28.4.12.5 Closed Circuit Television System End-Devices

CCTV images shall be available for viewing on individual workstations (multiple views available on 1 screen) or on selected parts of wall display. Image display shall be highly flexible and customizable.

Placement of the CCTV cameras shall be designed to maximize the operational and security objectives while providing the most efficient and cost-effective solution. The CCTV System shall be designed to provide the coverage and fields of views specified below. Each field of view is categorized under 1 of the general CCTV functions listed below:

- **Monitor** – The target person occupies at least 5 percent of the video monitor screen height, and the scene portrayed is not unduly cluttered. From this level of detail an observer shall be able to monitor the number, direction, and speed of movement of people, providing their presence is known to the observer (i.e., the target does not have to be searched for within the overall scene). For 4CIF (480 pixels vertically) resolution and a 5-foot-6-inch person, 5 percent of the video monitor screen height would be equivalent to approximately 4.5 pixels per foot.
- **Detect** – The target person occupies at least 10 percent of the video monitor screen height. After an alert, an observer shall be able to search within the displayed scene and ascertain with a high degree of certainty whether or not a person is present. For 4CIF (480 pixels vertically) resolution and a 5-foot-6-inch person, 10 percent of the video monitor screen height would be equivalent to approximately 9 pixels per foot.
- **Recognize** – The target person occupies at least 50 percent of video monitor screen height. An observer can determine with a high degree of certainty whether or not an individual shown is the same as someone they have seen before. For 4CIF (480 pixels vertically) resolution and a 5-foot-6-inch person, 50 percent of the video monitor screen height would be equivalent to approximately 40 pixels per foot.
- **Identify** – The target person occupies at least 120 percent of the video monitor screen height. The picture quality and detail shall be sufficient to enable the identity of an individual to be established beyond reasonable doubt. For 4CIF (480 pixels vertically) resolution and a 5-foot-6-inch person, 120 percent of the video monitor screen height would be equivalent to approximately 100 pixels per foot.

The minimum percentages of the video monitor screen height given above that the target shall occupy shall be obtained without the observer needing to zoom into the scene and assumes resolutions of at least 4CIF.

The above categories provide direction to the Designer for appropriate image sizes to when choosing the placement of cameras and the type of lenses to obtain the required field of view. The above categories do not imply that it will be impossible to recognize or identify an individual if the image size is smaller than the 50 percent or 120 percent

figures suggested. There is also no guarantee that individuals will be identifiable simply because they occupy >120 percent of the screen. Other factors, such as lighting, angle of view, and video compression will also have an influence. Therefore, the above categories shall be used as a guide to the Designer in determining preliminary locations of cameras and required lens characteristics. Fields of view shall be tested in the field to confirm whether the live and recorded images meet the intended function.

Field of View at Stations

The CCTV design shall provide the following fields of view at stations:

- Pedestrian Entrances/Exits
  - Description: Fixed color cameras shall be located to provide fields of view showing the frontal view of persons both entering and exiting stations
  - Function: Recognize
  - Resolution: 4CIF
  - Frame Rate: 5 frames per second
- Situational Awareness (Non-Platform)
  - Description: Pan-Tilt-Zoom color cameras shall be located to provide fields of view showing an overview of the station public areas. 100 percent coverage of public space is required to be covered, with an emphasis placed on the following locations: areas near entrances/exits, passageways, tops and bottoms of stairways, and areas in front of elevator and escalator landings, to monitor passenger movement.
  - Function: Monitor
  - Resolution: 4CIF
  - Frame Rate: 5 frames per second
- Situational Awareness (Platform)
  - Description: Pan-Tilt-Zoom color cameras shall be located on platforms to provide fields of view showing an overview of the platform areas. 100 percent coverage of the platform is required to be covered, with an emphasis placed on the following locations: platform edges, tops and/or bottoms of stairways, areas in front of elevator and escalator landings, to monitor passenger movement.
  - Function: Monitor
  - Resolution: 4CIF
  - Frame Rate: 15 frames per second
- Platform Edges

- Description: Fixed color cameras shall be located to provide fields of view showing the edge of the platform along the entire length of the platform for the purpose of providing the train door operator video to aid his determination that train doors to platform are clear and can be closed.
- Function: Detect
- Resolution: 4CIF
- Frame Rate: 15 frames per second

- Fare Control Areas (e.g., turnstiles)
  - Description: Fixed color cameras shall be located to provide fields of view showing the frontal view of persons (head to knees) both entering and exiting to/from the paid areas.
  - Function: Identify
  - Resolution: 4CIF
  - Frame Rate: 5 frames per second
- Inside Elevator Cab
  - Description: Fixed color cameras shall be located inside elevators to obtain full coverage of the entire cab interior to monitor passenger activity.
  - Function: Monitor
  - Resolution: 4CIF
  - Frame Rate: 5 frames per second
- Trespass Control (Unsecured Side)
  - Description: Fixed color cameras shall be located to provide fields of view of the unsecured side in front of an access control point (e.g., doorway, gate) to capture video of persons using the electronic access control device (e.g., card reader) and potential intruders entering the secured area.
  - Function: Detect
  - Resolution: 4CIF
  - Frame Rate: 5 frames per second
- Trespass Control (Secured Side – Identification)
  - Description: Fixed color cameras shall be located inside the secured area to provide fields of view of the secured entrance point (e.g., doorway, gate) to capture video of persons entering the secured area for the purpose of identification.
  - Function: Identify

- Resolution: 4CIF
- Frame Rate: 15 frames per second (15 frames per second is specified here assuming intruders may be moving quickly through the access control point to avoid being seen.)

- Trespass Control (Secured Side - Monitoring)
  - Description: Pan-Tilt-Zoom color cameras shall be located inside the secured room to monitor the activity of persons inside the room.
  - Function: Monitor
  - Resolution: 4CIF
  - Frame Rate: 5 frames per second
- Customer Assistance/Emergency Intercoms
  - Description: Fixed color cameras shall be located near CAI and EI Intercoms to monitor the activity of persons using the intercom. CAI/EI cameras may be Pan Tilt Zoom cameras able to monitor multiple CAI/EI devices and bring field of view surrounding of CAI/EI activated by button press. Details of this functional interface are to be covered in the functional and performance specifications.
  - Function: Recognize
  - Resolution: 4CIF
  - Frame Rate: 5 frames per second
- Ticket sales offices/ Ticket Vending Machines
  - Description: Fixed color cameras shall be located near ticket sales offices and ticket vending machines to capture video suitable to recognize the person making the transaction.
  - Function: Recognize
  - Resolution: 4CIF
  - Frame Rate: 15 frames per second

<u>Field of View at Parking Areas</u>

The CCTV design shall provide the following fields of view at parking areas:

- Vehicular Entrances/Exits
  - Description: Fixed color cameras supporting progressive scan shall be located to provide fields of view showing the driver as well as the license plate of the vehicle when the vehicle is entering and exiting the parking area. The area of interest (e.g., face or license plate) shall cover approximately 15 percent or more of the camera’s field of view.

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  - Function: Identify
  - Resolution: 4CIF
  - Frame Rate: 30 frames per second
- Parking Revenue Collection Sites
  - Description: Fixed color cameras shall be located to provide fields of view to capture video suitable to identify the person making the transaction.
  - Function: Identify
  - Resolution: 4CIF
  - Frame Rate: 15 frames per second
- General Observation of Parking Area
  - Description: Pan-Tilt-Zoom cameras supporting progressive scan shall be located to provide wide fields of view to capture video suitable to monitor the area where vehicles are parked. 100 percent coverage of the parking area is required.
  - Function: Monitor
  - Resolution: 4CIF
  - Frame Rate: 30 frames per second

<u>Field of Views along the Right-of-Way</u>

The CCTV design shall provide the following fields of view along the Authority's right-of-way:

- Tunnel Portals
  - Description: Fixed color cameras supporting progressive scan shall be located to provide fields of view to capture video of persons or vehicles entering and exiting the tunnel portal.
  - Function: Detect
  - Resolution: 4CIF
  - Frame Rate: 30 frames per second
- Traction Power Facilities
  - See requirements for Field of View at Stations for Trespass Control: Unsecured Side, Secured Side – Identification, and Secured Side – Monitoring Sections #7, #8, and #9.
- Enclosures at Standalone radio Sites

- See requirements for Field of View at Stations for Trespass Control: Unsecured Side, Secured Side – Identification, and Secured Side – Monitoring Sections #7, #8, and #9.

- ATC Equipment Houses
  - See requirements for Field of View at Stations for Trespass Control: Unsecured Side, Secured Side – Identification, and Secured Side – Monitoring Sections #7, #8, and #9.
- Tunnel Ventilation Facilities at Portal Sites and Ventilation Shafts
  - See requirements for Field of View at Stations for Trespass Control: Unsecured Side, Secured Side – Identification, and Secured Side – Monitoring Sections #7, #8, and #9.
- Tunnel Exit Shafts
  - 100 percent of Tunnel emergency exit shafts shall be covered. See requirements for Field of View at Stations for Trespass Control: Unsecured Side, Secured Side – Identification, and Secured Side – Monitoring Sections #7, #8, and #9

<u>Operations Control Center /Regional Control Center</u>

The CCTV design shall provide the following fields of view at the OCC/RCCs:

- Access Control Points
  - See requirements for Field of View at Stations for Trespass Control: Unsecured Side, Secured Side – Identification, and Secured Side – Monitoring Sections #7, #8, and #9.

<u>Field of View at Yards</u>

The CCTV design shall provide the following fields of view at the yards:

- Transition tracks
  - See requirements for Field of View at Stations: Unsecured Side, Secured Side – Identification, and Secured Side – Monitoring Sections #7, #8, and #9.
- Yard throat (where yard tracks come together at signaled area)
  - See requirements for Field of View at Stations: Unsecured Side, Secured Side – Identification, and Secured Side – Monitoring Sections #7, #8, and #9.
- General view of yard tracks to show occupancy and movement
  - See requirements for Field of View at Stations: Unsecured Side, Secured Side – Identification, and Secured Side – Monitoring Sections #7, #8, and #9.
- Transfer tracks between transportation and rolling stock maintenance departments

  - See requirements for Field of View at Stations: Unsecured Side, Secured Side – Identification, and Secured Side – Monitoring Sections #7, #8, and #9.

Field of View at Maintenance Facilities

The CCTV design shall provide the following fields of view at the MOI/RSM sites:

- Access Control Points
  - See requirements for Field of View at Stations for Trespass Control: Unsecured Side, Secured Side – Identification, and Secured Side – Monitoring Sections #7, #8, and #9.
- Fuel Dispensing Area
  - Description: Color cameras shall be located at the Fuel Dispensing Area to monitor the activity of personnel.
  - Function: Monitor
  - Resolution: See 4CIF
  - Frame Rate: 5 frames per second

28.4.13 Intrusion Detection System

The IDS shall be designed to monitor critical locations along the Authority's right-of-way and in facilities including perimeters and building interiors.

The IDS shall automatically detect physical, human intrusions at the following locations:

- Entrances into OCC and RCC buildings, maintenance facilities, stations, yards
- Traction Power Facilities
- Standalone radio site enclosures
- Equipment cabinets and enclosures
- Entrances to the back office areas (non-public areas) at stations
- Tunnel portals
- Tunnel Emergency Exit shafts
- Entrances to the following protected rooms and locations
  - Police and Security Offices
  - Ticket Sales Offices
  - Station Agent Offices
  - Entrance Facility Rooms

- Train Control and Communications Rooms
- Station Computer Rooms
- Communications Closets
- Mechanical Rooms
- Electrical Rooms
- Fire Protection Rooms
- Plumbing Rooms
- Elevator/Escalator Machine Rooms
- Battery Rooms
- Station Control Rooms
- Terminal Control Facilities
- Rooms containing money and safes

- Fenced areas
- Other locations considered necessary and as determined at a later date

The IDS shall also detect the intrusion of animals/livestock of significant size into the Authority's right-of-way.

The IDS shall not cause false alarms when trains cross tunnel portals.

The IDS shall not cause false alarms when rodents or other small debris cross tunnel portals.

The IDS shall be integrated with the EACS such that authorized persons may enter the above secure locations without generating an alarm, as appropriate.

28.4.13.1 Intrusion Detection System Architecture

There are no specific criteria. See Section 28.4.1.1.

28.4.13.2 Intrusion Detection System Spare Capacity, Expansion and Obsolescence

The IDS shall be designed to support the eventual proposed, full build out of the CHSTP system and, over and above that, to accommodate 25 percent more intrusion detection devices and processing of alarms.

28.4.13.3 Intrusion Detection System Command and Control

There are no specific criteria. See Section 28.4.1.3.

28.4.13.4 Intrusion Detection System Physical, Enclosure and Power

Enclosures for intrusion detection equipment shall be tamperproof.

28.4.13.5 Intrusion Detection System End-Devices

IDS end-devices shall be concealed and inaccessible by potential intruders.

28.4.14 Electronic Access Control System

The EACS shall control which personnel is permitted access to facilities and restricted areas; which areas they can access (e.g., rail yard facilities, communications rooms within stations); and when they can access these areas (e.g., certain days of the week or shifts). In addition to controlling passage in and out of facilities or areas, and determining who belongs and who does not, the EACS shall provide the ability to observe and track movement in and out of controlled areas. The EACS shall be designed to keep records of access for amount of time specified in the *Systems Safety and Security* Chapter.

The EACS shall be designed to provide easy access to public areas of facilities during hours of service operation while at the same time limiting access to non-public areas to authorized personnel only. During non-service hours, access to public areas shall also be controlled and granted to authorized persons only.

The EACS shall not interfere with fire protection and life safety systems.

Power over Ethernet (PoE) use is subject to codes, Authority Having Jurisdiction, and the amount of power delivered by PoE source versus the amount of power required by the electric lock.

The EACS shall conform to ADA requirements.

The EACS entry control shall be based upon a combination of the following:

- An agency-provided special ID card/badge to work with automatic readers (based on what you HAVE)
- A code, such as a personal identification number (PIN), for entering on a keypad (based on what you KNOW)
- A biometric device for feature recognition, such as fingerprint identification (based on who you ARE)

Different admission controlled barriers (e.g., doors, gates, portals) shall require different combinations of the above 3 entry-control mechanisms. Less secure areas may require only the use of an agency-provided identification card to grant access to the secure zone while more secure areas may require a combination of all 3 entry control mechanisms.

The EACS shall be designed to allow any combination of the above entry-control mechanisms at admission controlled barriers even if a single-entry control mechanism is deemed sufficient and installed during the initial deployment.

28.4.14.1 Electronic Access Control System Architecture

There are no specific criteria. See Section 28.4.1.1.

28.4.14.2 Electronic Access Control System Spare Capacity, Expansion and Obsolescence

The EACS system shall be designed to support the eventual proposed, full build out of the CHSTP system and, over and above that, to accommodate 25 percent more electronic access control devices and processing of access requests and alarms.

28.4.14.3 Electronic Access Control System Command and Control

There are no specific criteria. See Section 28.4.1.3.

28.4.14.4 Electronic Access Control System Physical, Enclosure and Power

There are no specific criteria. See Section 28.4.1.4.

28.4.14.5 Electronic Access Control System End-Devices

There are no specific criteria. See Section 28.4.1.5.

28.5 Communications Physical Support Rooms, Enclosures, Shelters and Equipment

The following sections include Design Criteria for:

- Communications Rooms
  - Entrance Facility Rooms
  - Train Control and Communication Rooms
  - Communications Closets
- Communications Interface Cabinets
- Communications Shelters
- Standalone Radio Sites
- Radio Towers
- Systems Conduits at Track

28.5.1 Communications Rooms supporting Communications Systems and Equipment

These sections contain the Design Criteria for rooms and pathways used to house and distribute cable, conduit, and equipment. These rooms shall be defined and designed for all buildings, including stations, facilities, tunnel ventilation facilities at portal sites and tunnel ventilation shafts, control centers, and similar. Grounding and bonding of communications rooms, conduit, cabling, shields, cabinets, enclosures, and similar shall be as in the *Grounding and Bonding Requirements c*hapter. ANSI/TIA/EIA-568-A Standard categorizes structured cabling rooms into six areas:

- Entrance Facility
- Equipment Room
- Backbone Cabling (connects entrance facilities, equipment rooms, and closets)
- Telecommunications Closet
- Horizontal Cabling (extends from the closets to the work areas and end devices)
- Work Area

Table 28-1 provides the nomenclature equivalency between the ANSI/TIA/EIA and project elements.

Table 28-1: Room Nomenclature

ANSI/TIA/EIA-568-A Designation	Project Equivalent
Entrance Facility	Entrance Facility Room
Equipment Room	Train Control and Communications (TCC) Room
Equipment Room	3rd Party Telecom Room
Telecommunications Closet	Communications Closet
Work Area	Terminal Control Facility
Work Area	Station Control Room
Work Area	Control Room
Work Area	Incident Command Post
Work Area	Incident Room

Table 28-2: Communications Related Spaces

Site Location	Rooms/Shelters/Equipment Location	Provisioning
OCC	• Entrance Facility Room • TCC Rooms (dual redundant) • Communications Closet(s) • 3rd Party Telephone Room	110/220 V ac 600A utility power, UPS, HVAC, waterless fire suppression, security.
RCC	• Entrance Facility Room • TCC Room • Communications Closet(s) • 3rd Party Telephone Room	110/220 V ac 600A utility power, UPS, HVAC, waterless fire suppression, security.
Intermediate Passenger Station	• Entrance Facility Room • TCC Room • Communications Closet(s) • 3rd Party Telephone Room	110/220 V ac 300A utility power, UPS, HVAC, waterless fire suppression, security
Terminal Passenger Station	• Entrance Facility Room • TCC Room • Communications Closet(s) • 3rd Party Telephone Room	110/220 V ac 400A utility power, UPS, HVAC, waterless fire suppression, security
Rolling Stock Maintenance or Maintenance of Infrastructure Facility	• Entrance Facility Room • TCC Room • Communications Closet(s) • 3rd Party Telephone Room	110/220 V ac utility power, UPS, HVAC, waterless fire suppression, access security.
Traction Power Facility	• Communications Shelter • Radio Tower	110/220 V ac utility power, UPS, HVAC, waterless fire suppression, security
ATC Equipment Houses	• Communications Shelter • Radio Tower	110/220 V ac utility power, UPS, HVAC, waterless fire suppression, security
Standalone Radio Site	• Communications Shelter • Radio Tower	Grading, drainage, access road, 110/220 V ac utility power UPS, HVAC, concrete slab, drainage access roads, security fence
Outdoor Yard	• Yard CICs: location based on necessary WLAN RF coverage and other end devices	110/220 V ac utility power, UPS, HVAC, underground conduit, drainage, concrete slab, security fence.
Tunnel Ventilation Facility	• Entrance Facility Room • TCC Room • Communications Closet(s)	110/220 V ac utility power, UPS, HVAC, waterless fire suppression, access security.

28.5.1.1 Communications Rooms

Each building (not including communications shelters) shall have an Entrance Facility Room where Authority and Third-Party service and cabling enters the building. The primary function of the Entrance Facility Room is demarcation from service providers and customer premises cabling and between inside plant and outside plant Authority cabling.

The Train Control and Communications Room (TCCR) houses the train control and communications equipment supporting wayside system and contains the bulk of communications equipment supporting the station or facility building. This room shall be shared between the train control equipment and communications equipment.

Communications closets are smaller communications rooms and are smaller than the TCCRs and generally contain less communications equipment than the main communications room and are placed based on horizontal cabling distance limitations. The primary function of the communications closet shall be termination and cross-connection of horizontal and backbone cables.

In general, train control and communications rooms and communications closets shall house communications (and other discipline) equipment in equipment cabinets. Equipment cabinets may be free-standing or wall mounted and shall be designed to the criteria listed in Section 28.4.1.4.

28.5.1.2 TCC Rooms, EF Rooms and Communications Closets

TCC Rooms, Entrance Facility Rooms, and communications closets and contents shall be designed to the seismic and structural requirements declared in the *Structures* chapter. The rooms shall have a minimum floor loading as described in the *Structures* chapter. If raised access flooring is used in the room, it must be rated accordingly.

Provide ac-grade plywood, 8 feet high with a minimum thickness of 0.75 inches (¾”) around the perimeter of the room. Plywood shall be fire-rated and may NOT be painted. The bottom of the plywood shall be mounted 6 inches above the finished floor.

The rooms shall be dedicated to the TCCR function and related support facilities and not shared with electrical or HVAC installations nor shall water pipes, ductwork, pneumatic tubing, or similar pass through the Entrance Facility room, TCCR, or communications closet.

At minimum, the rooms shall be sized based on BICSI standards and the number of work areas and end devices plus expansion as detailed in Section 28.4.1.2.

The rooms shall not be located below water level and shall be free of water supply or drain pipes unless needed to support the installed equipment.

A floor drain shall be provided within the room if risk of water ingress exists.

The room shall be located with ready access to the main HVAC delivery system or dedicated HVAC equipment.

The room shall be located away from sources of EMI such as electrical transformers, motors, and induction sealing devices.

Environmental control equipment, such as power distribution or conditioner systems, and UPS up to 100 kVA shall be permitted in the room.

Doors providing access to other areas of the building through the room shall be avoided to limit access to authorized personnel only.

Minimum clear height in the rooms shall be 9 feet without obstructions.

If contaminants are present in greater concentrations as indicated in ANSI/TIA/EIA-569-A, the room shall be provided with vapor barriers, positive room pressure, or absolute filters.

If sprinklers are required by local code, the heads shall be provided with wire cages to prevent accidental operation and drainage troughs shall be placed under sprinkler pipes to prevent leakage onto equipment. Consideration shall be given to the installation of alternate fire-suppression systems (i.e., "clean agent").

Communications equipment requires the HVAC 24 hours per day, 365 days per year including during times when equipment is powered by UPS or other emergency or standby power source.

Rooms require at minimum a double door 72 inches wide and 90 inches high without doorsill and with a removable center post.

Firestopping shall be used whenever a fire-rated wall, ceiling, or floor is penetrated by communications facilities. The firestop shall be installed to maintain the rating of the structure penetrated, see the *Structures* chapter. A qualified system or design approved and tested by an independent laboratory for use in the specific penetration shall be used.

Floor materials having antistatic properties shall be selected.

<u>Entrance Facility Rooms</u>

If third-party and Authority cabling terminations are co-located within the Entrance Facility Room, there shall be a secure, physical separation between spaces accessible by third-party personnel and Authority equipment.

At each Entrance Facility Room the Designer shall provision for:

- Outside Plant Cable Termination
- Inside Plant Cable Termination

Train Control and Communications Rooms

Avoid placing main rooms in building areas that limit expansion such as elevators, core, outside walls, or other fixed building walls. The room shall be accessible for delivery of large equipment.

Communications Closets

A communications closet shall be located on each floor as close as practical to the center of the floor space and preferably in the core area of the building. Additional communications closets shall be provided when the floor area being served exceeds 10,000 square feet or the horizontal cabling distance to the end devices exceeds 295 feet. Multiple communications closets on a floor shall be interconnected by a minimum of two Trade Size 4 conduits or equivalent pathway.

28.5.2 Communications Interface Cabinets

Provide Communications Interface Cabinets (CICs), which are stand-alone cases that only house equipment and are used primarily for providing network connectivity to end devices. CICs are located indoors as wall-mounted CICs, may be located outdoors at facilities (referred to simply as CICs), or located along the Authority's right-of-way and in tunnel cross-passages (referred to as wayside CICs). CICs are not located within communications rooms.

CIC weight and location shall be coordinated with the structural loading specified in the *Structures* chapter.

CICs shall be designed to protect enclosed equipment per the criteria described in Section 28.4.1.4.

28.5.3 Communications Shelters

Communications provides network connectivity for communications' and other disciplines' equipment at various sites throughout the Authority's right-of-way via a communications shelter. A communications shelter is relatively larger than a CIC and can accommodate personnel as well as equipment.

Communications shelters shall be designed to the seismic, structural and physical Design Criteria listed in the *Structures* chapter.

Communication shelters and equipment cabinets and enclosures shall be access controlled and remotely monitored at OCC and RCC for intrusion detection.

28.5.4 Standalone Radio Sites

The ORS must be configured as a secure, multi-functional network to connect wayside elements with mobile units throughout the geography of operation.

Space accommodations shall be provided for a communications shelter and radio tower at a spacing of approximately 5 miles, accomplished through the co-location of radio sites within or adjacent to Traction Power Facilities (TPFs) (Substations, Paralleling Stations, and Switching Stations), ATC equipment houses, and at tunnel portal sites. Additional stand-alone radio sites containing radio towers and supporting communications shelters shall be placed approximately in between these co-located sites. These Standalone Radio Sites shall be placed only relative to the TPFs, ATC equipment houses, and tunnel ventilation facilities at tunnel portal sites such that the linear distance between any 2 radio towers is nominally 2.5 miles and no greater than 3 miles.

If spacing between adjacent TPFs, ATC equipment houses and tunnel portal sites is:

- Greater than 0 miles and less than or equal to 3 miles – No Standalone Radio Site required (do nothing)
- Greater than 3 miles and less than or equal to 6 miles – Place a Single Standalone Radio Site equidistant between adjacent sites
- Greater than 6 miles – Multiple Standalone Radio Sites shall be placed between the existing sites to achieve a uniform spacing no greater than 3 miles between all sites.

Standalone radio sites shall not be placed within 250 feet of overhead power lines. Standalone radio sites shall not be placed at tunnel sections. Standalone radio sites shall be located to facilitate access by maintainers.

Access to each stand-alone radio site shall be required both during construction and for operation and maintenance purposes.

See *Civil* chapter for access road, parking, and gate and fence criteria. See the *Drainage* chapter for drainage requirements.

Stand-alone radio sites shall be designed to minimize the adverse visual impact on the areas in which they are located and to be in compliance with the appropriate architectural, environmental and commercial guidelines as specified in the Environmental Assessment/Final Environmental Impact Report and local jurisdictional ordinances.

Safety signage shall be provided at stand-alone radio sites in accordance with applicable codes and standards.

28.5.5 Radio Towers

Radio towers are located at the sites described in Section 28.5.4 and may also be located at stations and facilities based on final design.

The ORS radio towers shall be maximum 100-foot-tall monopoles or equivalent.

The Designer shall confirm that all site selection, environmental approvals, zoning board approvals, planning commission, Federal Aviation Administration and Federal Communications Commission approvals are complete as part of the design process. If elements are incomplete, unapproved, or non-compliant, the Designer shall bring the radio site to full compliance with all applicable codes. A radio tower shall not be placed within 250 feet of overhead power lines.

The Designer shall calculate wind load and ice accumulation to the Electronics Industry Association Structural Standards for Steel Antenna Tower and Antenna Supporting Structures - EIA/TIA-222-E.

To factor in the proper ice loading consideration, the tower designer shall refer to the EIA/TIA-222-F Code appendix. The Designer must consider ice load and wind velocity.

The Designer shall conduct and provide a geological analysis of the soil at the radio tower site. The Designer shall design the tower foundation to perform to the functional and performance specs and soil conditions. The radio tower foundation shall be designed to the seismic, structural and physical Design Criteria listed in the *Structures* chapter.

The Designer shall determine and incorporate Federal Aviation Administration requirements for marking and lighting the radio tower. The lighting shall be remotely monitored via the appropriate SCADA subsystem as discussed in the *Supervisory Control and Data Acquisition Subsystems* chapter.

The Designer shall design a transmission line bridge to support and protect the cable for the horizontal run from the tower to the building entry ports. This cable must be resistant to climatic and field environmental factors and be vandal proof.

28.5.6 Systems Conduits at Track

HST Core Systems (Traction Electrification, Overhead Contact System, Automatic Train Control and Communications) requires cable conduits for low-voltage, data and control cables to pass from one side of the track to the other at selected wayside sites and facilities. Conduits shall provide cable paths between the cable troughs, surface mounted devices and the wayside site or facility. Depending on the site and section features, these pathways may consist of the following elements:

- At-Grade – manholes, undertrack conduit ductbank, at-grade cable trough segments to join the cable troughs
- Trench – manholes, underground conduit ductbanks, undertrack conduits, surface-mounted conduits, pullboxes and / or non-structural members carrying conduit above track.

- Aerial – structure mounted conduit, pullboxes and underground conduit ductbank
- Tunnels – To be determined by Tunnel Design

The Designer shall provide conduits at the following locations:

- O&M Facilities
  - Operations Control Center/Heavy Maintenance Facility
  - Regional Control Centers
  - Rolling Stock Maintenance Facilities
  - Maintenance of Infrastructure Facilities
- Stations
- Wayside Sites
  - Traction Power Facilities
  - Train Control Facilities
  - Standalone Radio Sites
- Tunnel Ventilation Facilities
  - Tunnel Ventilation Facilities at Portals
  - Tunnel Ventilation Facilities at Ventilation Shafts

28.5.6.1 At-Grade and Trench Conduit Ductbank and Manholes

At-grade, the Designer shall provide concrete-encased, undertrack conduit ductbank consisting of Trade Size 4 conduits terminating at manholes at the locations and quantities shown in Table 28-3.

At trenches, the Designer shall provide concrete-encased, underground conduit ductbank, consisting of Trade Size 4 conduits terminating at manholes at the locations and quantities shown in Table 28-3. At trench sections, if underground conduit ductbank penetrates trench wall, waterproofing of trench wall shall be maintained.

Manhole covers shall be lockable and be labeled "California High Speed Rail – Low Voltage Cabling"

Table 28-3: Quantities of Undertrack and Underground Conduit at At-Grade and Trench Sites and Locations

Wayside Site, Location or Facility	Minimum Number of Trade Size 4 Conduits
Traction Power Facility	12
Train Control House	20
Standalone Radio Site	12
Operations Control Center / Heavy Maintenance Facility	12 Or Two Banks Of 12*
Regional Control Center	12 Or Two Banks Of 12 *
Rolling Stock Maintenance Facility	12 Or Two Banks Of 12*
Maintenance of Infrastructure Facility	12 Or Two Banks Of 12*
Station	Two Banks Of 12**

Notes:

* Provide a single 12 conduit ductback for an O&M Facility wholly existing on one side of the main line tracks. In the case that the main line track divides an O&M Facility, install two 12 conduit undertrack conduits spaced 1000 feet apart, centered at the facility.

** At each end of a station platform, provide an undertrack conduit ductbank containing 12 conduits.

Conduit ductbank and manholes shall be designed, manufactured and tested in accordance with, NEC, NEMA, ASTM and EIA/TIA 758. There shall be a maximum of two 90 degree (or equivalent) bends in low-voltage systems conduits between pull boxes, handholes, manholes and cable vaults. Manholes shall be designed to accommodate connection to cable trough and connection of the same number and size of conduits within ductbank to wayside site or facility located outside of the Authority's right-of-way.

Conduit ductbank containing 12 conduits shall be arranged 4 conduits wide by 3 conduits high. Conduit ductbank containing 20 conduits shall be arranged 4 conduits wide by 5 conduits high.

<u>Longitudinal Location of Conduit Ductbank and Manholes</u>

Locate conduit ductbank and manholes longitudinally within the limits of the site as shown on the contract drawings. If alternative systems site locations exist locate conduit ductbank and manholes within the limits of each site alternative.

When a relocated roadway separates the Authority's Right-of-Way and a wayside site or facility location, additionally install a conduit ductbank of the same configuration beneath the roadway to a third manhole located outside of the relocated roadway's right-of-way.

Conduit ductbank shall be located at least 2 feet away from other 25kV underground ductback.

<u>Vertical Location of Conduit Ductbank</u>

Conduit ductbank shall be located minimum 6 feet below top of rail and when not underneath rail, conduit ductbank shall be located minimum 3 feet below grade.

<u>Horizontal Location of Manholes</u>

At at-grade open drainage, inbound wall of manhole shall be located at minimum of 2 feet from drain aggregate.

At at-grade closed drainage, included retained fill or retained cut, inbound wall of manhole shall be located at minimum 2 feet from underdrain.

Manholes shall be located within Authority's right-of-way or Wayside site or facility land (in the case of providing underground ductbank beneath a relocated roadway.

<u>Vertical Location of Manholes</u>

Manhole top surfaces shall nominally be a minimum of 2 inches above grade.

28.5.6.2 Aerial Cable Conduits

The Designer shall design the aerial structures to accommodate the surface mounted, Trade Size 4 conduit, or equivalent, between opposing cable troughs and wayside sites and locations at the locations and quantities shown in Table 28-3.

Underground conduit ductbank design at aerial sections shall be coordinated with underground elements of aerial structures per the *Structures* chapter.

Aerially mounted conduits shall be coordinated with the loading specified in the *Structures* chapter.

28.5.6.3 Tunnel Cable Conduits

Undertrack conduits at tunnel sections are part of the tunnel design.

28.6 External Services

28.6.1 Telecommunications Services

The Designer shall accommodate and design interfaces to the following telecommunications services:

- Voice-grade telephone service at the control centers, stations, maintenance facilities, and yards to allow Authority personnel to make outgoing calls and receive incoming calls from/to selected Authority ATELs
- VPN data service used to interconnect control centers as a backup data communications path in case a control center becomes isolated from the WAN
- Internet Access
- Cellular Telephone Service for management staff

In addition to normal voice-grade telephone service, the Designer shall accommodate and design interfaces to the Government Emergency Telecommunications Service (GETS). GETS is a White House-directed emergency phone service provided by the National Communications System (NCS). GETS supports federal, state, local, and tribal government, industry, and non-governmental organizations personnel in performing their National Security and Emergency Preparedness (NS/EP) missions. GETS provides emergency access and priority processing in the local and long distance segments of the Public Switched Telephone Network. It is intended to be used in an emergency or crisis situation when the Public Switched Telephone Network is congested and the probability of completing a call over normal or other alternate telecommunication means has significantly decreased.

If wireless cellular service is required, then the Designer shall also design interfaces to the Wireless Priority Service (WPS), which is another National Communications System-sponsored program that increases the ability to make calls when cellular networks are congested.

External telecommunications services that shall be interfaced with shall include Priority Restoration Level X as defined under the Telecommunications Service Priority (TSP) program. The TSP program is a federally-established program under which the Office of Priority Telecommunications in the Executive Office of the President prioritizes the restoration and provisioning of telecommunications services—including services to private companies and institutions—that support NS/EP. Priority Restoration designation establishes priorities for restoring NS/EP service in the event of an outage or failure of multiple services. According to the Priority Restoration service level, the telecommunications service provider will dispatch personnel outside normal business hours if necessary to restore circuit(s) (and provide any related special construction) assigned a Priority Restoration level of 1, 2, or 3. The telecommunications service provider will dispatch personnel outside normal business hours to restore circuits (and provide any related special construction) assigned a Priority Restoration level of 4 or 5 only when the next business day is more than 24 hours away.

28.6.1.1 Backup Virtual Private Network Connections

A VPN telecommunications service shall be interfaced to and used to interconnect control centers to provide a backup communications path allowing communications between control centers in the event that any control center loses network connectivity via their primary network path over the WAN. Consideration shall be given to telecommunications services that allow for dynamic bandwidth provisioning, where the Authority can request the service provider to increase the provided bandwidth when the primary communications path via the WAN is not available.

28.6.2 External Notification Services

The Designer shall integrate into the IIMPs the following Emergency Notification services on behalf of the authority:

- Commercial Mobile Alert System
- National Weather Service
- Emergency Managers Weather Information Network
- Naval Meteorology and Oceanography

28.6.3 Infotainment

The Authority ultimately may facilitate onboard broadband information and entertainment (infotainment) access to passengers via a data radio service separate from the Authority RS described previously. These infotainment services may be provided by an independent franchisee. The Designer shall not preclude the addition of this service.

Chapter 29

Rolling Stock–Core Systems Interfaces

HSR 13-06 - EXECUTION VERSION

Revision	Date	Description
0	02 Mar 12	Initial Release, R0

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Acronyms

AREMA C&S	American Railway Engineering and Maintenance-of-Way Association Communications and Signals
ATC	Automatic Train Control
ATO	Automatic Train Operation
ATS	Automatic Train Supervision
CHST	*Not Used; use HST for California High-Speed Train*
CHSTP	California High-Speed Train Project
EIRENE	European Integrated Railway Radio Enhanced Network
EMC	Electromagnetic Compatibility
EMF	Electromagnetic Field
ERTMS	European Rail Traffic Management System
HST	High-Speed Train
ICD	Interface Control Documents
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IIMP	Integrated Information Management Platforms
OBS	Onboard Systems
OCC	Operation Control Center
OCS	Overhead Contact System
RAMS	Reliability, Availability, Maintainability, and Safety
RS	Rolling Stock
SS	Substation
TES	Traction Electrification System
TPS	Traction Power Supply System
UIC	International Union of Railways
WCS	Wireless Communications Systems
U_m	mean useful voltage
U_n	nominal voltage
U_{max1}	highest permanent voltage
U_{max2}	highest non-permanent voltage
U_{min1}	lowest permanent voltage
U_{min2}	lowest non-permanent voltage

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29 Rolling Stock – Core Systems Interfaces

29.1 Scope

The passenger Rolling Stock (RS) shall interface with the core systems consisting of Traction Power, Overhead Contact System (OCS), Automatic Train Control (ATC), and Communications. This chapter addresses these core systems interfaces only. The design criteria for passenger RS interfaces with infrastructure including clearances, wheel/rail interaction, structure loading requirements, noise, shock, and vibration are described in the RS specifications.

The design criteria for passenger RS interfaces shall cover the functional, mechanical, electrical, and logical interface requirements between the passenger RS and the core systems that allow the California High-Speed Train (HST) System to meet the functional and performance requirements of the project, including Reliability, Availability, Maintainability, and Safety (RAMS). RAMS requirements are described in the specific discipline chapters of these design criteria and in the rolling stock specifications.

29.2 Regulations, Codes, Standards, and Guidelines

Refer to the *General* chapter for requirements pertaining to regulations, codes, and standards.

- International Union of Railways (UIC) Code
    - UIC 612-0 – Driver Machine Interfaces for EMU/DMU, Locomotives, and Driving Coaches – Functional and system requirements associated with harmonized Driver Machine Interfaces
- American Railway Engineering and Maintenance-of-Way Association Communications and Signals (AREMA C&S) Manual of Recommended Practices
    – Part 17 – Recommended
- U.S. Department of Defense (USDOD) Standards
    – MIL-HDBK-217F – Military handbook – Reliability Prediction of Electronic Equipment
    – MIL-STD-785B – Reliability Program for System and Equipment Development and Production
    – MIL-STD-756B – Reliability Modeling and Prediction
    – MIL-STD-1629A – Procedures for Performing a Failure Mode, Effects and Criticality Analysis
- European Committee for Electrotechnical Standardization (CENELEC) Standards

- EN 50121-3-1 – Railway applications - Electromagnetic compatibility. Rolling stock. Train and complete vehicle
- EN 51021-3-2 – Railway applications - Electromagnetic compatibility. Rolling stock. Apparatus
- EN 50121-5 – Railway applications - Electromagnetic compatibility. Emission and immunity of fixed power supply installations and apparatus.
- EN 50121-4 – Railway applications – Electromagnetic compatibility – Part 4: Emission and immunity of the signaling and telecommunications apparatus
- EN 50125-1 – Railway applications – Environmental conditions for equipment – Part 1: Equipment on-board rolling stock
- EN 50125-3 – Railway applications – Environmental conditions for equipment – Part 3: Equipment for signalling and telecommunications
- EN 50126-1 – Railway applications – The specification and demonstration of Reliability, Availability, Maintainability and Safety – Part 1: Basic requirements and generic process (1999)
- CLC/TR 50126-2 Railway applications – The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS) – Part 2: Guide to the application of EN 50126-1 for safety (2007)
- EN 50128 – Railway applications – Communications, signalling and processing systems – Software for railway control and protection systems (2010)
- EN 50129 – Railway applications – Communications, signalling and processing systems – Safety related electronic systems for signalling (2003)
- EN 50159 – Railway applications – Communications, signalling and processing systems – Safety-related communication in transmission systems (2010)
- EN 50238 - Railway applications - Compatibility between rolling stock and train detection systems (2003)
- EN 50388:2005 – Railway applications – Power supply and rolling stock. Technical criteria for the coordination between power supply (substation) and rolling stock to achieve interoperability

• International Electrotechnical Commission (IEC) Standards

- IEC 60812 – Analysis techniques for system reliability – Procedures for failure mode and effect analysis

• European Rail Traffic Management System (ERTMS) Specifications

- EEIG 96S126 – ERTMS/ETCS RAMS Requirements Specification

• Institute of Electrical and Electronics Engineers (IEEE) Standards

- IEEE 519 - IEEE recommended Practices and Requirements for Harmonic Control in Electrical Power Systems
- IEEE 1558 – IEEE Standard for Software Documentation for Rail Equipment and Systems
- ANSI/IEEE 1028 – IEEE Standard for Software Reviews – The Institute of Electrical and Electronics Engineers
- IEEE 1003 – IEEE Standard for Information Technology – Portable Operating System Interface (POSIX)
- IEEE 1008 – IEEE Standard for Software Unit Testing
- IEEE 1228 – IEEE Standard for Software Safety Plans

- Federal Transit Administration (FTA)
  - UMTA-MA-06-0153-87-2 – Conductive Interference in Rapid Transit Signaling Systems Volume II: Suggested Test Procedures
  - UMTA-MA-06-0153-85-8 – Inductive Interference in Rapid Transit Signaling Systems Volume II: Suggested Test Procedures
  - UMTA-MA-06-0153-85-11 – Radiated Interference in Rapid Transit Signaling Systems Volume II: Suggested Test Procedures

29.3 General Interface Design Requirements

The design of interfaces between the passenger RS and core systems shall be reflected in the individual systems and subsystems designs and shall be recorded in a series of Interface Control Documents (ICDs). Ownership of the ICDs shall rest with the passenger RS contractor; the contractors supplying traction power, OCS, train control and communications shall have input to the ICDs and shall participate in detail interface agreement and design meetings.

29.4 Traction Power Interfaces

29.4.1 Purpose

The purpose is to define the Traction Power Supply System (TPS) interface requirements with the passenger RS.

29.4.2 Power Supply

Trains shall be able to operate within the range of voltages and frequencies as given below:

- System Voltage
  - The nominal voltage (U_n), that is, the designated value for the system voltage, shall be 25 kilovolts (kV).

- The highest permanent voltage (U_{max1}), that is, the maximum value of the voltage likely to be present indefinitely, shall be 27.5 kV.
- The highest non-permanent voltage (U_{max2}) that is, the maximum value voltage likely to be present for a limited period of time (as defined below), shall be 29.0 kV.
- The lowest permanent voltage (U_{min1}), that is, the minimum value of voltage likely to be present indefinitely, shall be 19.0 kV.
- The lowest non-permanent voltage (U_{min2}) that is, the minimum value of voltage likely to be present for a limited period of time (as defined below), shall be 17.5 kV.

- Voltage Related Requirements – The following voltage related requirements shall be fulfilled:
  - The duration of voltages between U_{min1} and U_{min2} shall not exceed 2 minutes.
  - The duration of voltages between U_{max1} and U_{max2} shall not exceed 5 minutes. If voltage between U_{max1} and U_{max2} is reached, it shall be followed by a level below or equal to U_{max1} for an unspecified period. Voltages between U_{max1} and U_{max2} shall only be reached for non-permanent conditions such as regenerative braking.
  - The voltage at the busbar of the substation at no-load conditions shall be less than or equal to U_{max1}.
  - Under normal operating conditions, voltages shall lie within the range $U_{min1} \leq U \leq U_{max2}$.
  - Under abnormal operating conditions, the voltage in the range $U_{min2} \leq U \leq U_{min1}$ shall not cause any damage or failure, and shall permit continuing vehicle operation with some significant degradation. Rated vehicle power and performance will not be available but reduced operation will be possible assuming onboard logic will automatically degrade the performance of the traction system and auxiliaries. Typical abnormal operating conditions could include: substation outage, utility supply problems, etc. See also section 29.4.3. There will be no degrading of auxiliary power until U_{min2} is reached.
  - The setting of under-voltage relays in fixed installations or onboard RS should be from 85 percent to 95 percent of U_{min2}.
  - Both the following acceptance criteria for 'Quality Index of Power Supply' for ac 2 X 25 kV autotransformer feed configuration shall be satisfied (see Section 8 of EN 50388):

    U_m = > 22.5 kV

    U_i => 19 kV (U_{min1} – Lowest permanent voltage)

    Where, Mean Useful Voltage (U_m) is the mean value of all root mean square (rms) voltages analyzed in the system simulation study, and gives an indication of the quality of the power supply for the entire system during the peak traffic period in the timetable, and

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$U_m = \Sigma U_i/N$ where U_i is the rms ac voltage over the i^{th} second during the peak period for all trains in the system, and N is the total number of observations.

- Frequency:
  - The nominal frequency of the supply voltage shall be 60 Hertz (Hz).

    For systems with synchronous connection to an interconnected system, under normal operating conditions the mean value of the fundamental frequency measured over 10 seconds shall be within the following ranges unless the requirements of the power supply utility are more stringent.

    i. 60 Hz +/- 1% (e.g., 59.4 Hz … 60.6 Hz) for 99.5 percent of a year

    ii. 160 Hz +4% / -6% (e.g., 56.4 Hz … 62.4 Hz) for 100 percent of the time

29.4.3 Train Power and Current Limitation

The maximum allowable train current including auxiliaries, for both traction and regeneration modes, shall be equal to the maximum current capacity of the Traction Electrification System (TES), which is 1500 amperes (see Section 7 of European Standard 50388).

In order to facilitate stable operation in abnormal operating conditions, trains shall be equipped with an automatic device which adapts the level of the power consumption depending upon OCS voltage in steady state conditions.

If U = OCS voltage at any instance in kV,

I_{max} = maximum current consumed by the train at 25 kV,

I_{aux} = current consumed by the auxiliaries of the train, and

I = current drawn by the train at voltage U, then

$I = I_{aux} + (I_{max} – I_{aux})*(U – 17.5)/22.5\text{-}17.5)$ for $17.5\text{ kV} \le U \le 22.5\text{ kV}$

and

$I = I_{max}$ for $22.5\text{ kV} < U \le 29\text{ kV}$.

This equation does not apply in regenerative braking mode.

29.4.4 Regenerative Braking

General conditions on the use of Regenerative Brakes include the following:

- Trains shall not continue to use their regenerative brakes if the following occurs (also see Section 12 of EN 50388):

- There is a loss of supply voltage or an OCS-rail/ground short-circuit on the same section fed by the substation
- The OCS fails to absorb the energy,
- The line voltage is higher than 29 kV

• If feedback energy absorption by other consumers is not available, the RS shall revert to other brake systems.

- TPS shall be designed in such a way that regenerative braking can be used as a service brake.
- Regenerative braking mode shall be permitted from the beginning of train operations.

29.4.5 Power Factor

Table 29-1 gives the requirements of inductive power factor, λ, of any train. (Also see Section 6 of EN 50388):

Table 29-1: Power Factor of Trains

Instantaneous Train Power 'P' at the Pantograph (in MW)	λ
P > 6	≥ 0.95
2 < P ≤ 6	≥ 0.93

In order to control the total power factor of the auxiliary load of a train during the coasting phases, the overall average 'λ' (traction plus auxiliaries) shall be higher than 0.85 over a complete time table journey.

For yards and maintenance facilities, when a train is stationary, with traction power off, and the active power taken from the OCS is greater than 10 kW per vehicle, the total power factor resulting from the train load shall not be less than 0.8 but with a target value of 0.9.

During regeneration, inductive power factor may be allowed to decrease freely in order to keep voltage within limits.

29.4.6 Electrical Protection Coordination

• The protection system for the TES shall be designed for a maximum OCS – rails short-circuit fault current of 15 kA.

• Compatibility of protective systems between traction unit (RS) and Substation (SS) shall be verified with the RS Contractor for the following (see Section 11 of EN 50388):

- When any internal fault occurs within the traction units, both the SS feeder circuit breaker and the traction unit circuit breaker may trip immediately. However, as far as

possible, the traction unit circuit breaker should trip in order to prevent the substation circuit breaker from tripping.

  - After the substation circuit breakers have tripped these shall be capable of being reclosed either automatically or manually only after a lapse of at least three seconds.
  - The traction unit circuit breakers shall trip automatically within three seconds after loss of line voltage.
  - On re-energization, the traction unit circuit breaker shall not reclose within three seconds of the line being re-energized.
- Conformity assessment shall be carried out for design and operation of substations in accordance with EN 50388:2005, clause 14.6.

29.4.7 Overvoltages Generated by Harmonics

The passenger RS shall conform to the acceptance criteria specified in Section 10.4 of the European Standard EN 50388 – Railway Applications - Power Supply and Rolling Stock - Technical Criteria for the Coordination between Power Supply (Substation) and Rolling Stock to Achieve Interoperability.

The passenger RS Contractor / designer shall interface with the TPS designer to demonstrate that the harmonics generated by the combined RST and TES comply with harmonic limits per Tables 10.3, 10.4 and 11.1 of IEEE standard 519, "IEEE recommended Practices and Requirements for Harmonic Control in Electrical Power Systems", unless the limits imposed by the concerned power supply authority are more strict.

29.5 Overhead Contact System Interfaces

For the technical criteria regarding the very critical dynamic interaction between the passenger RS pantograph and the overhead contact line, refer to the *Overhead Contact System and Traction Power Return System* chapter of these Design Criteria and the CHSTP Rolling Stock Specification Section 9; General Electrical Equipment.

For a train consist with multiple pantographs, no electrical connection may exist between pantographs in service.

The main circuit breaker of the passenger RS shall automatically open before the train unit enters a phase break or system break in the OCS. This shall be controlled by an input received from the ATC subsystem.

Where a train has stopped within the limits of a neutral section of a phase break or system break, a rescue power supply shall be provided via remotely controlled and operated OCS switching arrangements. Trains and the remotely controlled disconnect switches will be

operated under "Caution" to ensure there is no bridging between two OCS sections that are energized from different power supply systems.

29.6 Automatic Train Control Interfaces

29.6.1 Purpose

The purpose is to define the ATC interface requirements with the passenger RS.

29.6.2 General Requirements

This document defines the minimum ATC interface requirements that shall be provided with the passenger RS.

- Interfaces are divided into four general categories: mechanical, electrical, functional, and electromagnetic:
  - The mechanical interfaces cover space provisions (lockers) and mounting points (including brackets).
  - The electrical interfaces cover wiring and cabling as well as power and voltage requirements.
  - The functional interfaces describe protocols for specific functions and data exchanges required at the passenger RS subsystems interfaces to ensure that the overall system functional requirements are met.
  - Electromagnetic interfaces cover design provisions to ensure that passenger RS conducted and inductive emissions do not interfere with the safe and dependable operation of the ATC equipment, particularly track circuits and transponders.

29.6.3 Interface Requirements

29.6.3.1 Interface Requirements of the Rolling Stock Contractor

The passenger Rolling Stock Contractor shall do the following:

- Provide physical and functional interfaces in the passenger RS equipment to allow the ATC equipment to perform its ATP, ATS, ATO, and other functions.
- Work with the ATC Contractor to establish passenger RS conducted and inductive emission limits, which ensure the safe and dependable operation of the ATC equipment under normal and worst case failure conditions.
- Provide passenger RS operational data, transfer functions, tolerances, failure modes, and any other data necessary for the ATC contractor to evaluate safe braking distances and to implement correct functional operation.

- Provide space and attachment points for all passenger RS-mounted ATC equipment; space shall include sufficient volume of unoccupied space to allow for equipment temperature considerations.
- Provide compartments with the required environment for all interior-mounted ATC equipment.
- Provide interconnecting conduit, wiring, terminal strips, connectors, trainlines, and related wiring items to both interconnect ATC equipment sets and connect the passenger RS with the ATC equipment.
- Participate in passenger RS static and dynamic investigative, qualification, and acceptance tests (i.e., participate in the development of procedures, participate in the tests, and participate in the development of the test reports that demonstrate that the interfaces function properly and that the passenger RS performs properly with the integrated systems).
- Develop and maintain the detailed ATC-RS interface information in a controlled document format. Prepare and perform test and inspection procedures for verifying that the ATC-TR interface requirements are met prior to the passenger RS delivery.

29.6.3.2 Interface Requirements of the Automatic Train Control Contractor

The ATC Contractor shall do the following:

- Provide physical and functional interfaces in the ATC equipment to allow the passenger RS to operate under ATP, ATS, ATO, and other functions.
- Work with the passenger RS Contractor to establish passenger RS conducted and inductive emission limits, which ensure the safe and dependable operation of the ATC equipment under normal and worst-case failure conditions.
- Provide space and attachment point requirements for all passenger RS-mounted ATC equipment. Identify the volume of unoccupied space needed to allow for equipment temperature considerations.
- Identify the required environment for all interior-mounted ATC equipment.
- Provide interconnecting terminal strips, connectors, trainlines, and related wiring items to both interconnect ATC equipment sets and connect the passenger RS with the ATC equipment.
- Participate in passenger RS static and dynamic investigative, qualification, and acceptance tests (i.e., participate in the development of procedures, participate in the tests, and participate in the development of the test reports that demonstrate that the interfaces function properly and that the passenger RS performs properly with the integrated systems).
- Develop and maintain the detailed ATC-RS interface information in a controlled document format.

- Prepare and perform test and inspection procedures for verifying that the ATC-TR interface requirements are met prior to the passenger RS delivery.

29.6.4 Interface Management Process

All ATC-Rolling Stock interfaces shall be recorded in an ICD, or set of ICDs that are updated as necessary to record any changes in the design, manufacture, testing, and commissioning of the passenger RS. The passenger RS contractor shall maintain and control these documents with regular review by the ATC contractor. The ATC contractor will also develop an interface document that references the RS Contractor's ICD.

29.6.5 Automatic Train Control Technology Information

The onboard equipment shall generally consist of a set of vital processor equipment, data communications equipment for networking around the train on ATC dedicated networks and for interfacing to the train control networks, data radios and antennas, speed sensors, track circuit code pick-up antennas, and transponder (balise) reading antennas. GPS receivers may also be provided by the ATC contractor. Voice and other data radios for communications between operations and maintenance personnel may be provided by the ATC contractor if ERTMS, which uses the European Integrated Railway Radio Enhanced Network (EIRENE) specifications, is supplied as the train control system. Alternatively, voice and other data radios may also be provided by the communications contractor if the voice and other data transmission are not integral with the ATC system.

29.6.6 Rolling Stock Interface Requirements to Onboard Automatic Train Control

The passenger RS contractor shall provide terminal blocks in an ATC terminal panel adjacent to the ATC enclosure and install wires that shall connect from this terminal block to all the ATC system peripherals including antennas, sensors, ATC specific trainlines, and passenger RS subsystems including networks. Allowances shall be for 100 wires from ATC peripheral devices which are assumed to be 14 AWG in size. All ATC specific trainlines shall be wired to the ATC terminal panel by the passenger RS contractor. The passenger RS contractor shall provide wiring and make connections to the ATC terminal panel for all functions necessary to control the train. This shall include trainlines and local wiring. The functions that need to be controlled and/or sensed by ATC include the following:

- Propulsion
- Brakes
- Doors
- Low voltage power
- Train event recorder
- Train health monitoring and maintenance diagnostic subsystem

- Opening and closing of main circuit breaker for phase break operations
- Pantograph up and down controls
- Air vent controls
- Flange lubrication controls
- Onboard system abnormality detectors including vehicle instability, hot bearings, etc.

Switching of connections between non-ATC and ATC control modes shall be achieved within the ATC enclosure. In order to allow this to be done, the passenger RS contractor shall connect both the control wiring to the train subsystems (normally trainlines) and the manual control wiring for these functions, to the ATC termination panel. Prior to the installation of the ATC equipment, appropriate jumpers shall be required at the ATC terminal blocks to ensure reliable connections when the passenger RS is test run prior to ATC installation.

An additional 10 percent spare number of terminals shall be provided.

29.6.7 Safe Braking Design

The passenger RS contractor will provide the following information in a timely manner:

- Nominal emergency brake rate(s)
- Brake effort build up times
- Maximum acceleration of the train
- Single point brake system failure modes and other impacts on emergency brake rates
- Nominal service brake rates

29.6.8 Rolling Stock Parameters

The passenger RS contractor will supply the following core set of data (nominal, minimum, and maximum characteristic values will be required):

- Complete tractive effort characteristics as a function of speed and load for motoring and braking
- Complete acceleration characteristics corresponding to the tractive effort curves
- Response time from emergency brake trainline opening to failsafe propulsion removal; similarly from brake pipe vent to failsafe propulsion removal
- Response time from emergency brake trainline opening to initial brake buildup; similarly from brake pipe vent to initial brake buildup
- Buildup time from initial brake buildup to full emergency brake application
- Response times from ATC command change to tractive effort change

- Rate of tractive effort changes under all conditions
- Transfer function from ATC command to tractive effort output
- Requirements and limitations for signals transmitted across couplers
- Wheel Spin/Slide System operational characteristics and failsafe time-out characteristics
- Percentage brake rate reduction resulting from brake system failures. This calculation shall be performed as a probabilistic risk assessment for critical circuits and systems, including brake component failures, in order to assess what braking rate should be used in the safe braking analysis.
- Selected failure mode information for other circuits and systems
  - Propulsion and Braking Test Data, including tests under both normal and low adhesion conditions)
  - Eddy current brake performance data including Failure Mode, Effects, and Criticality Analysis information
  - Electromagnetic Compatibility (EMC) characteristics and parameters
  - Design information for speed and acceleration limiting functions to protect end-of-line approaches
- Low adhesion conditions with equipment failures that impact emergency brake rates will be used in the ATC design shall be determined as a consensus between the HST, the passenger RS, and the ATC contractors.

Minimum mean deceleration values are defined in the CHSTP RS Specification Section 11: Braking.

29.6.9 Environmental

Onboard ATC equipment shall comply with the environmental ranges as described in the CHSTP RS Specification Section 4: Climate and Environment — of particular note is the temperature range of -25 to +75 degrees Celsius.

29.6.10 Mechanical Interfaces

Sufficient space/volume shall be provided to accommodate the mechanical dimensions, including provisions for air cooling circulation of ATC equipment.

A. ATC Control and Radio Equipment

ATC Electronics – Provide a securable locker at each end of the train, adjacent to the cabs for the main ATC electronics unit. The locker shall include space for all electronics and other equipment, an ATC terminal panel allowing ATC supplied harnesses to be connected to the ATC terminal panel and to be plugged into the ATC equipment, and sufficient volume for air

circulation. The passenger RS contractor shall cable between the passenger RS subsystems and the ATC terminal panel.

The ATC interface specifications shall identify the dimensions of the locker.

The ATC radio equipment shall be co-located in the ATC locker with the ATC electronics unit.

The ATC interface specifications shall identify a weight to be assumed for each of the ATC equipment sets.

A space on the floor of the ATC equipment locker of 6 inches by 12 inches with clearance height of 4 inches immediately below or adjacent to the ATC volume for mounting an ATC accelerometer will be provided along the longitudinal. The 12-inch dimension shall be parallel to the train side.

ATC Communications Interface Unit – Provide a securable locker at each end of the train, adjacent to the ATC equipment locker for ATC communications interfaces equipment. The locker shall include space for all electronics and other equipment, a terminal panel allowing ATC supplied harnesses to be connected to the ATC communications interface terminal panel and to be plugged into the ATC communications interface equipment, and sufficient volume for air circulation. The passenger RS contractor shall cable between the passenger RS subsystems and the ATC communications interface terminal panel.

The ATC interface specifications shall identify the dimensions of the locker.

Assume 16 lbs for each set of ATC communications interface equipment.

This locker shall be within a maximum of 10 feet cable distance from the main ATC enclosure.

Mounting Arrangements – The passenger RS Contractor shall provide floor mounting points for the ATC equipment rack to be mounted on.

Maintenance Access – Provide access to the allocated space for the ATC equipment for front and rear access for easy installation, test, and subsequent maintenance. Provide access to the cable termination area.

Bonding – Provide a train ground bonding point and termination to allow the ATC contractor to bond the equipment frame (rack) to the train ground.

Heat Dissipation and Thermal Interfaces – Provide sufficient natural ventilation capability such that the ATC equipment when outputting 500 watts will exist in an ambient temperature of between +70 and -40 degrees Celsius.

B. ATC Console Controls

Provide space on the console for the installation of a control panel containing a set of ATC control switches, an audible alarm, and associated wiring access and terminations. The panel location shall be readily accessible to a seated Locomotive Engineer, when facing forward. The

volume provision for the ATC controls panel shall be identified in the ATC interface specifications. The passenger RS contractor shall provide cabling and wiring consisting of 30 insulated 14 AWG wires between the panel location and the ATC terminal block. The wires shall be terminated on a terminal block adjacent to the console ATC panel location.

The ATC Contractor shall assemble the panel with the required number and type of switches, etc. for mode selection and other ATC functions for the Locomotive Engineer's input and acknowledgement.

The Locomotive Engineer's console shall be designed in compliance with UIC 612; "Functional and System Requirements allocated to harmonized Driver-Machine-Interfaces".

ATC Display – Make provision to mount an ATC display in a location where the Locomotive Engineer can readily see this display, while looking forward, from a seated position. The ATC display shall be supplied by the ATC contractor and be integrated into the Locomotive Engineer's console in accordance with UIC 612.

Cable and wiring, details of which shall be identified in the ATC interface specifications, shall be provided by the passenger RS contractor between a terminal block adjacent to the display and the terminal block adjacent to the ATC primary equipment location.

Provision shall be made for the ATC contractor to install a sealed Bypass switch in the rear wall of the cab.

C. Speed Sensors

Locations – Provide for 2 speed sensor positions on 2 non-powered axles for ATC, for a total of 4 sensors per each operating unit. These speed sensors positions must be dedicated to ATC. The non-powered axles are preferably those closest to each of the ATC cabinets.

Provision shall also be made for two Doppler radar devices per lead unit mounted beneath the body facing towards the cab end with no metal mass or electrical device within 3 feet in front of the units.

Wiring – The passenger RS contractor shall provide cabling and wiring between the sensor points and the ATC cabinet terminal block.

D. ATC Data Radio Antenna

Locations – Provide a location for an antenna mounting on the roof of the cab car at each end of the train (locomotive) above the location of the ATC electronics enclosure.

Dimensions – The exterior dimensions of the antenna are up to 4 inches in diameter and up to 12 inches long. The antenna will be mounted longitudinally on the roof. A support bracket will be used to mount the antenna on the car (locomotive).

Mounting Arrangements – The passenger RS contractor shall provide the mounting point to allow the ATC contractor to secure the bracket to the roof. The ATC antenna mount can be adapted to a design of the attachment points provided by the passenger RS contractor.

Weight — The combined weight of the antenna and bracket will be identified in the ATC interface specifications.

Maintenance Access – Provide access to the space above the ceiling for installation of the antenna, running and terminating a large coaxial cable, and access for long term maintenance.

Wiring – The passenger RS contractor shall provide cabling and wiring between the antenna points and the ATC cabinet terminal block. The cable requirements shall be defined in the ATC interface specifications.

E. ATC Transponder (Balise) Interrogator Antenna

Locations – The passenger RS contractor shall provide a mounting point for a transponder interrogator antenna. The minimum distance required between the antenna and any propulsion related equipment including cables and motors shall be identified in the ATC interface specifications.

Below the antenna, a clear material (metal and otherwise) free path is required from the bottom face of the antenna to the track bed in a square cone expanding out from the bottom of the antenna at an angle of 30 degrees in all 4 directions.

The cable requirements between the antenna location and the ATC locker terminal panels shall be defined in the ATC interface specifications.

F. ATC Cab Signal Antennas

Locations – The passenger RS contractor shall provide mounting points for 2 antennas, 1 in front of each wheel on the number 1 axle on each cab car. The mounting points shall be protected behind a pilot bar to give physical protection to the antennas from loose objects on the ballast and ties. Clearances required between the ATC cab signal antennas and any propulsion related equipment including cables and motors shall be identified in the ATC interface specifications.

Below the antenna a clear material (metal and otherwise) free path is required from the bottom face of the antenna to the track bed in a square cone expanding out from the bottom of the antenna at an angle of 30 degrees in all 4 directions.

The cable requirements between the antenna locations and the ATC locker terminal panels shall be identified in the ATC interface specifications.

Bonding – The passenger RS contractor shall provide a bonding termination adjacent to the antenna mounting position for the ATC contractor to connect to.

29.6.11 Electrical / Functional Interfaces

A. Bypass Mode

Provide for an ATC Bypass (or cutout) mode in which there is no ATC supervision or enforcement. The passenger RS subsystem shall enforce a speed limit of 59 miles per hour (mph) on train operation in this mode.

When in Bypass mode, the ATC display shall inhibit the speedometer.

B. Network and Discrete Trainlines

The following minimum trainline provisions shall be provided in the passenger RS design for ATC functions:

- Bypass – 2 discrete
- Twisted Shielded Pairs (TSPs) – 4 for ATC communication – 2 and radio network – 2
- Mode selection – a total of 6
- Master Controller status – cab active – 2 vital lines to ATC
- ATO start – 2
- Door enable – Correct side door enable/supervision will be a function of ATC and the passenger RS contractor shall provide additional trainlines for this function. In addition to the 2 already allocated for the car, an additional 2 shall be provided for vital side control.
- Provision – 4 trainlines for function transfer from cab to cab

C. Power Supply Interfaces

Provide power to each ATC cabinet at a nominal voltage of 36 volts. Provide space for 3 circuit breakers per cab car for the ATC System, assuming the maximum power consumption shall be an average of 900 watts per train end. The breakers shall be rated at 15 A, 15 A, and 10 A.

D. Interfaces to Operators Console

Provide routing between the operator's console and the local ATC cabinet, for a nominal cable/conduit comprising a minimum of 30 discrete wires. Assume 14 AWG wire size. Also provide routing from the ATC enclosure to the console for the ATC display.

The RS supplied speedometer shall be inhibited when the train is operating in ATC, ATC–ATO, and Restricted Manual modes.

E. Master Controller Key-Up

A double cut input (2 wires) shall be provided to the ATC indicating that the local cab is activated (status high = active).

F. Master Controller Position

Provide a logical input to ATC that indicates that the Master controller is in the Full Service Brake (FSB) position. In the absence of this input, ATC will assume the master controller is in a position other than FSB.

G. Mode Selection Interfaces

The ATO mode selection switches will be provided by the ATC contractor and mounted on the console.

H. ATO Start Pushbuttons

The ATO start buttons will be provided by the ATC contractor and mounted on the console. These switches will be connected to the ATC cabinet by means of cables installed by the passenger RS contractor.

I. Emergency Brake Interfaces

Provide an ATC interface to the emergency brakes such that ATC can hold off the applications of emergency brakes when operating in an ATC mode. In Bypass mode, passenger RS shall prevent ATC from applying the emergency brakes.

J. Service Brake Interfaces

Provide a logical (network) interface to ATC that will enable the train subsystems to respond to braking commands from ATC. The train shall respond to ATC braking commands if they are of higher demand than currently being requested by the master controller (operator input). The braking system shall also be capable of sending status to the ATC.

K. Propulsion System Interfaces

Provide a logical (network) interface to ATC that will respond to tractive effort commands from ATC when operating in ATO.

The train shall also provide to ATC an input when the master controller is in the full service brake position. The train shall respond to ATC braking commands if the train detects that ATC is operating in ATO, the train shall recognize the status of the ATO start trainline to indicate that ATO is operational.

ATC shall be capable of requesting the cut-off of propulsion.

L. Train Door System Interfaces

Provide for both opening and closing, separate side enable lines that are double cut to enable ATC to treat them vitally. The requirement is to provide two trainlines for each side that shall be operated by ATC to ensure that the doors can only be opened on that specific side when the train is under ATC control in ATC territory.

M. Event and Incident Detectors

The passenger RS shall provide input to the onboard ATC equipment in the event of events and incidents occurring onboard that the ATC shall respond to and/or transmit an alarm/event

announcement to the ATC–ATS. The details of specific responses shall be determined during the contractor's design phase.

The interfaces provided shall include the following:

- Hot bearing detectors
- Penalty and emergency brake applications
- Locomotive Engineer alerter activated
- Car body and truck accelerometers for instability detection.
- Ten additional detectors to be defined during the detailed design phase

N. Maintenance/Diagnostic System Interfaces

Provide a logical (network) interface between the ATC and the onboard maintenance and diagnostic system. This will be sized to allow for up to 200 elements relating to onboard subsystems (1 element equating to door system failure in Car 1 for example). The interface will also be sized to allow for transfer of up to 40 ATC elements including software versions of ATC onboard equipment.

The onboard systems data will be transmitted via the ATC wayside for monitoring of train systems health status to the Operations Control Center (OCC) and/or the car shops.

The following events will be transmitted by ATC to the control center ATS:

- Low Voltage Power Supply /Battery Charger Failed
- Low Battery
- Up to 10 additional diagnostic interfaces to be determined during the detailed design phase.

O. Event Recorder Interfaces

Provide discrete and logical (network) interfaces to provide the following ATC related data to the onboard event recorder:

- ATC Operating Mode
- ATC penalty brake application.
- Emergency Brake Application
- ATC Tractive and Braking Effort Level Command
- ATC Measured Speed
- ATC Door enable left
- ATC Door enable right
- ATC Bypass Switch status

- ATC Mode Switch status
- ATC Time Signal
- ATC Spare 1
- ATC Spare 2
- ATC Spare 3

29.6.12 Commands from Automatic Train Supervision to Rolling Stock

The following commands and groups of commands can be sent from the ATS workstations to the train for action by the passenger RS subsystems:

- **Announcement and Passenger Sign Interfaces** – Provide a logical (network) interface to enable ATC to send 12 triggers to the passenger RS audible announcement and visual message display systems to activate 12 pre-recorded announcements. The actual text of the announcements shall be determined during the detailed design phase.

29.6.13 Train Subsystems Interface

Provide a logical interface to enable ATC to send commands to the train subsystems for the following:

- To close and open vents and other elements for ventilation control when approaching and leaving tunnels.
- For switching of high voltage power breakers as necessary for section gaps.
- To lower and raise pantographs.

For switching this and other equipment, the commands can be sent from the onboard ATC to the passenger RS subsystems based on physical location on the right-of-way.

29.6.14 Track Circuit – Rolling Stock Electromagnetic Compatibility

The ATC and passenger RS Contractors will jointly establish specific immunity limits to protect ATC equipment; particularly track circuits and track-based data communication circuits, from train-generated interference. These limits will be implemented by coordinated action by the passenger RS and ATC Contractors during ATC and passenger RS design, implementation, and qualification testing.

For EMC between passenger RS and ATC track circuits, EN - 50238, Railway applications - Compatibility between rolling stock and train detection systems, shall govern the relationship. The ATC Contractor shall use EN 50238 procedures to document and convert the electromagnetic immunity characteristics of planned wayside equipment into corresponding emission limits which will apply to passenger RS. The passenger RS Contractor shall ensure that

the passenger RS emissions comply with the limits developed by the ATC Contractor. If necessary, the Contractors shall modify ATC and passenger RS designs to ensure compatibility.

U.S. Department of Transportation Federal Transit Administration test procedures govern testing of the compatibility of trains and track circuits. The passenger RS Contractor shall perform field qualification tests to demonstrate that the passenger RS conforms to the emission limits using the following procedures:

- UMTA-MA-06-0153-85-6 – Conductive Interference in Rapid Transit Signaling Systems Volume II: Suggested Test Procedures
- UMTA-MA-06-0153-85-8 – Inductive Interference in Rapid Transit Signaling Systems - Volume II: Suggested Test Procedures
- UMTA-MA-06-0153-85-11 – Radiated Interference in Rapid Transit Signaling Systems Volume II: Suggested Test Procedures

29.6.15 Rolling Stock - Electromagnetic Field Exposure

Implanted medical device manufacturers and U.S. research laboratories have established exposure limits for people with implanted medical devices such as pacemakers. The recommended limit is 1.0 G for frequencies up to 10 kHz, including the Project traction power frequency of 60 Hz.

The passenger rolling stock contractor shall determine whether an Electromagnetic Field (EMF) level above the recommended 1.0 G limit can occur inside the passenger RS passenger compartments. The passenger RS contractor shall perform a detailed design assessment during the design and construction phases to determine worst case level. The analysis shall confirm EMF levels inside the passenger compartment, considering the worst case EMF due to OCS and rail currents and the shielding effect of the railcar body. After construction, the contractor shall test the passenger RS to determine the actual worst case EMF level inside the passenger compartment.

If the actual worst case EMF level exceeds the established limit, the Project safety program will ensure that passengers or employees with implanted medical devices are aware of the potential exposure to a magnetic field above the established limit by placing suitable warning signs in the passenger compartments and on platforms.

29.7 Communications Interfaces

Passenger RS to wayside communications interface design criteria give the Designer the guidance to successfully design the onboard passenger RS system interfaces to meet the functionality and performance requirements described in the functional specifications. The functional and performance specifications for onboard systems provide the details of such interfaces. The *Communications* chapter contains general design criteria for communications

systems and the functional specifications for functional, performance and other requirements of the communications systems. Additional functional and performance criteria are defined in the CHSTP RS Specification Section 16; "Communications".

An interface, from the perspective of system development, consists of 3 elements; electrical, mechanical, and logical and is identified as any point where 2 or more systems meet. This interface point may include, internal hardware, circuitry, external peripherals, networks, logical interfaces between networks, users, or similar. There are several systems onboard the passenger RS, which require interface to wayside communications systems and several passenger RS system elements that will be located at fixed locations and need to interface with communications systems, integrated information management platform workstations and users. All interfaces shall be identified, managed during changes, and tracked during the design process. Furthermore, to ensure the constructed system satisfies the system requirements, these interfaces shall be tested and verified by the system integrator after construction. The onboard systems have systems-to-systems interfaces, and system-to-physical interfaces.

A Systems-to-Systems Interface is defined as an interaction between stand-alone systems that performs a unique function. A systems-to-systems interface is facilitated by physical contact closure, or electrical or optical data transfer.

A Systems-to-Physical Interface is defined as a physical space interaction between systems equipment and the physical spaces and features of the passenger RS. This type interface is outside of the scope of this chapter since the onboard systems and passenger RS will be designed and procured as part of a single contract.

This section discusses the design criteria and guidelines for the onboard system-to-system interfaces.

The passenger RS will be specified with multiple onboard systems (OBSs) that will have an interface and/or need to be integrated with the wayside communications systems (described in the *Communications* chapter of these Design Criteria). The OBSs include but are not limited to the following:

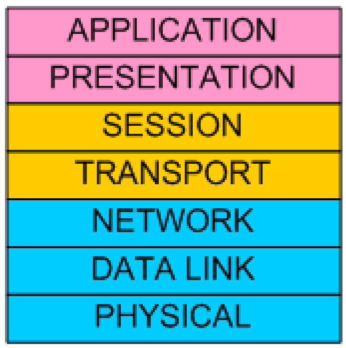
- Onboard Radio
- Onboard Public Address
- Onboard Passenger Information System
- Onboard Controller
- Digital Enhanced Cordless Telephone
- Onboard Fire Alarm System
- Onboard Passenger Emergency Intercom
- Onboard Trainline network

These OBSs shall interface to the wayside communications systems to provide seamless functionality between fixed operations control locations and onboard devices. Proper interface design and control is required to achieve this functionality.

29.7.1 System to System Interfaces

OBSs shall interface to the fixed wayside via the Wireless Communications Systems (WCS), each interface is considered as an end-to-end functionality, and not simply between the onboard radio equipment and the wayside equipment. In conducting the design of these systems and interfaces, the designer shall coordinate multiple interfaces encompassing multiple protocols between the passenger RS and wayside communications systems including, wireless networks, wired networks, and control systems (Integrated Information Management Platforms [IIMPs]).

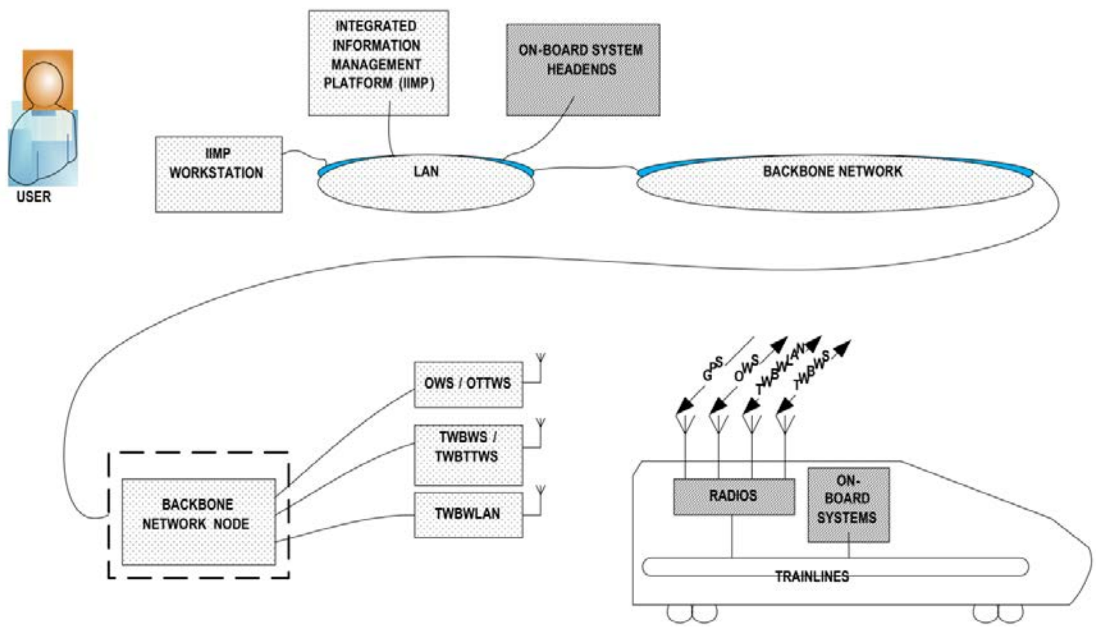
Figure 29-1: Open Systems Interconnection Reference Model



With reference to Figure 29-1; the end-system device shall implement protocols that perform the functions throughout all 7 layers (i.e., perform the application level processes associated with the top 2 layers, end-to-end logical connectivity functions associated with the Session and Transport layers, as well as the networking functions associated with the bottom 3 layers). The network equipment used to interconnect the end-system devices will perform various functions associated with the lower 3 layers. The main purpose of the figure is to illustrate that end-system devices, which could possibly be procured under different contracts, also contain "network functions". These end-systems are therefore part of the end-to-end network and shall be interoperable with the network equipment to ensure end-to-end delivery of the application data.

When considering interfaces between the wayside communications systems and the onboard systems, it is important to consider the system boundaries. A typical, high-level, end-to-end system diagram for onboard passenger RS systems to wayside communications systems is shown in Figure 29-2.

Figure 29-2: Wayside Communications and Onboard Systems Interface Diagram

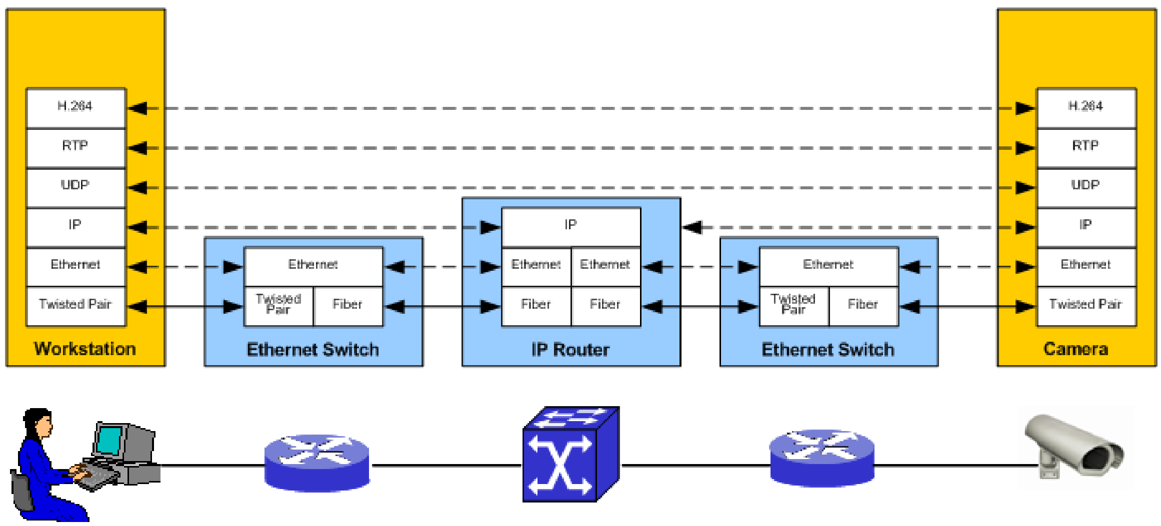


Within Figure 29-2, wayside communications systems are indicated in a dotted pattern and the onboard systems are shown as diagonal strips. Note that the onboard systems also have a presence at the fixed locations. The onboard systems require system head-ends (servers, databases, central processing elements) installed at control centers to interface via the wired and wireless networks to the onboard end-devices.

To support the end-to-end exchange of data, components shall support an interface with each other and exchange data using a common protocol across the interfaces. The interface shall include a physical connection between 2 communicating components (e.g., between a server and network switch) or shall be via a logical communications path across a network when the 2 communicating components are connected to a common wired or wireless network. Agreement between multiple protocols, referred to as a protocol stack, is required to support fully end-to-end communications between 2 components.

Figure 29-3 illustrates an example protocol stack (i.e. layers of protocols) used to support the transmission of a video stream from a camera to a workstation for live viewing. (This is an example only and the mention of any specific protocols here shall not be considered as a requirement to support the protocol.) Both the workstation and camera are considered end-systems from the networking point of view. A network end-system (or host) is a device running an application layer process that transmits and/or receives data across the network to another network end-system. The network is required to securely and reliably move the data between the application processes running on the network end-systems.

Figure 29-3: Example Protocol Stack and Interfaces



Consideration of the multiple interfaces and protocol compatibilities to achieve functionality is crucial to insuring the onboard systems interface to the wayside communications systems and provide full functionality. Please see the *Communications* chapter of these Design Criteria for the "CHSTP Network".

29.7.2 Rolling Stock Communications Systems Interface Design Criteria

Systems-to-systems interfaces shall be considered end-to-end to meet the functionality and performance requirements described in the functional specifications. The onboard systems shall be designed to function with the wayside communications systems.

29.7.2.1 OBS to Wayside Communications Wireless System Interface Design Criteria

It is anticipated that only the onboard voice, data and high-bandwidth data radios will directly interface with the WCS. The onboard systems will be served by these radio interfaces.

Real-time downloads shall consist of urgent status reports by exception only; a failure occurs and failures are cleared. This limited, real-time data can be carried by the Operations Wireless System.

Intermittent download of MMIS onboard data and recorded Closed Circuit Television (CCTV) data can occur when trains are in yards (or at stations) for archiving in a central facility. Details of this functionality will depend on the train to wayside radio system.

Onboard radios shall interface with the types of wireless systems specified.

Onboard radio characteristics shall be compatible with the over the air interfaces and the end to end functional and performance characteristics.

29.7.2.2 OBS Fixed Elements to Wayside Communications Systems Interface Design Criteria

The OBSs shall interface via the wayside communications wireless and wired networks to onboard system head-ends located at fixed facilities.

The head-ends shall process, store and relay data gathered from the onboard system devices.

The head-ends shall be designed to interface with the wayside communications IIMPs such that all indication and control can be performed from the communications IIMP.

The onboard system head-ends shall be designed with Application Programming Interfaces (APIs) to allow the control and monitoring functionality required in the specifications to be accessed via the IIMPs.

Chapter 30

Reliability, Availability, Maintainability, and Safety

HSR 13-06 - EXECUTION VERSION

Revision	Date	Description
0	02 Mar 12	Initial Release, R0

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Tables

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Figures

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Acronyms

30 Reliability, Availability, Maintainability, and Safety (TBD)

TBD. This topic may be included in a future revision of the Design Criteria or will be included in another document.

Chapter 31

Systems Assurance

HSR 13-06 - EXECUTION VERSION

Revision	Date	Description
0	02 Mar 12	Initial Release, R0

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Acronyms

31 Systems Assurance (TBD)

TBD. This topic may be included in a future revision of the Design Criteria or will be included in another document.

Chapter 32

System Safety and Security

Revision	Date	Description
0	02 Mar 12	Initial Release, R0

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Acronyms

Authority	California High-Speed Rail Authority
Certification	Safety and Security Certification
CHST	*Not Used; use HST for California High-Speed Train*
CPTED	Crime Prevention Through Environmental Design
HRI	Hazard Risk Index
HST	High-Speed Train
SSMP	CHSTP Safety and Security Management Plan
TVA	Threat and Vulnerability Assessment
VVMP	CHSTP Verification &Validation Management Plan

32 System Safety and Security

32.1 Safety and Security Policy Statement

It is the policy of the California High Speed Rail Authority (Authority) to perform work on the California High Speed Train Project (CHSTP) in a manner that ensures the safety and security of employees, contractors, emergency responders, and the public. The application of system safety and security is a fundamental hazard and vulnerability management process that incorporates the characteristics of planning, design, construction, testing, operational readiness, and subsequent operation of the high-speed rail system. Safety and security are priority considerations in the planning and execution of all work activities on the CHSTP.

All trains, facilities, systems and operational processes must be designed, constructed, and implemented in a manner that promotes the safety and security of persons and property. The design, construction, testing, and start-up of the CHSTP will comply with applicable safety and security laws, regulations, requirements and railroad industry practices. The Authority will maintain or improve upon the public transit and railroad industry standards for safety and security. Through the Reliability, Availability, Maintainability, and Safety Program, a standard of safety will be established that is as safe as or safer than conventional U.S. railroad operations. The design, construction, testing, and start-up of CHSTP will be accomplished in compliance with this standard.

The Authority is committed to providing a safe and secure travel and work environment. Therefore safety, accident prevention, and security breach prevention must be incorporated into the performance of every employee task. All Authority, Program Management Team, and Contractor personnel, subcontractors, and employees are charged with the responsibility for ensuring the safety and security of employees, contractors, emergency responders, and the public who come in contact with the CHSTP. Each individual and organization is responsible for hazard and vulnerability management, for applying the processes that are designed to ensure safety and security, and for maintaining established safety and security standards, consistent with their position and organizational function. Through a cooperative team effort and the systemic application of safety and security principles, the CHSTP will be designed, constructed, tested, and placed into service in a safe and secure manner.

32.2 Scope

The process for assuring that the California High-Speed Train (HST) System is designed, built and prepared for operation in a safe and secure manner is described in the CHSTP Safety and Security Management Plan. This chapter presents general design guideline processes for safety and security considerations for the CHSTP trackway and facilities. Specific design criteria for safety and security considerations are found in the respective technical chapters of the Design Criteria.

32.3 Regulations, Codes, Standards, and Guidelines

Refer to the *General* chapter for requirements pertaining to regulations, codes, and standards. Applicable codes and regulations include but are not limited to the following list:

- Occupations Health administration (OSHA) CFR Title 29, Part 1910 *General Industry*, and Part 1926 *Construction*
- Federal Railroad Administration (FRA) CFR Title 49, Part 220 (under development)
- Federal Railroad Administration (FRA) CFR Title 49, Part 236, subparts H and I
- Federal Transit Administration (FTA), Circular 5800.1 *Safety and Security Management Guidance for Major Capital Projects*
- Federal Transit Administration (FTA), *Handbook for Transit Safety and Security Certification*
- Transportation Security Administration (TSA) security directives for existing railroads, security recommendations for high-speed rail (under development)
- 49CFR Parts 15 /1520 Protection of Security Sensitive Information
- California Building Codes
- California Code of Regulations, Title 8, Tunnel Safety Orders
- California Public Utilities Commission (CPUC) General Orders
- MIL STD-882D, System Safety Program Requirements
- MIL-STD-1629A Procedures for Performing a Failure Mode, Effects, and Criticality Analysis
- EN 50126-1 Railway applications - The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS)
- Hazard Analysis Guidelines for Transit Projects, January 2000, U.S., Department of Transportation/FTA
- American National Standards Institute (ANSI) Standard Z590.3-2011 *Prevention Through Design*
- National Fire Protection Association (NFPA) 1 Fire Code, 3 Recommended Practice on Commissioning and Integrated Testing of Fire Protection and Life Safety Systems, 70 National Electrical Code, 101 Life Safety Code, and 130 Standard for Fixed Guideway Transit and Passenger Rail Systems as applicable to the particular characteristics of the high-speed train system

32.4 Goals

The goals of System Safety and Security are to achieve acceptable levels of hazard and security risk resulting in the:

- Prevention of fatalities or injuries to passengers, employees, emergency responders, and the general public.
- Prevention or minimization of damage to infrastructure and interruptions in service.
- Protection of people (employees, contractors, emergency responders and passengers) and Authority property (facilities and equipment) from criminal acts.

32.5 Hazard Management

A hazard is a condition or circumstance that could lead to an unplanned or undesired event which, when it occurs, can cause injury, illness, death, damage or loss of equipment or property, or severe environmental damage.

Hazards shall be managed to an acceptable level of risk in order to provide the Authority with a reasonable assurance that the HST System is designed, built, and placed into service in a safe and secure manner. An acceptable level of risk is achieved through:

- The identification of hazards that can reasonably be expected to occur during the life-cycle of the HST System ;
- Analyzing the hazards for severity and probability in order to assign a Hazard Risk Index (HRI);
- Application of appropriate mitigations that reduce the HRI to an acceptable level; and,
- Tracking the application of mitigations to ensure that efforts to reduce the HRI to an acceptable level are complete.

Hazard Management shall employ the following hierarchy of controls when considering the application of appropriate mitigations:

- Avoidance
- Elimination
- Substitution
- Engineering Controls
- Warnings

- Administrative Controls such as Operations & Maintenance Procedures
- Personal Protective Equipment and Guards

Hazards associated with each major element that can reasonably be expected to occur in the life cycle of the HST System shall be identified, analyzed and tracked through a System Hazard Analysis process as described in the SSMP. Output from the System Hazard Analysis will take the form of measures of mitigation that are incorporated into the Final Design of the certifiable elements. These safety mitigations are found in the respective technical chapters of the Design Criteria.

32.6 Threat and Vulnerability Management

Threats are defined as specific intentional acts that will damage the system, its facilities, or its patrons. Threats include any intentional actions which detract from overall security. They range from the extreme of terrorist-initiated bombs or hostage-taking to more common events such as theft of services, pick pocketing, graffiti and vandalism. Vulnerability is defined as the susceptibility of the system to a particular type of security threat.

A Threat and Vulnerability Assessment (TVA) shall be developed to evaluate the susceptibility to potential threats and to design corrective actions that can reduce or mitigate the risk of serious consequences from a security incident. The TVA consists of four activities

- Identification of critical assets of the HST System
- Identification and analysis of the threats against these assets
- Identification of potential vulnerabilities within the HST System
- Identify measures to mitigate threats

The TVA shall identify the likelihood of specific threats that may endanger railroad assets (people and property); the potential vulnerabilities associated with the design of the HST System; and measures of mitigation that can be designed into the HST System to reduce the risk and to minimize the consequences of identified potential criminal and terrorism activities. These security mitigations are found in the respective technical chapters of the Design Criteria.

Crime Prevention Through Environmental Design (CPTED) principles shall be employed in the design of the HST System.

The TVA shall be protected under the Authority's Sensitive Security Information (SSI) Policy and shared only with those persons with a need to know.

32.7 Safety and Security Certification

The goal of the Safety and Security Certification Program (Certification) is to verify that identified safety and security requirements have been met in the preliminary engineering, final design, and construction phases and to provide evidence that the HST System is safe and secure for revenue service. With respect to the Final Design and Construction phases the objective of Certification is to document that safety and security certifiable elements of facilities, equipment, and operations have been designed, constructed, manufactured, inspected, installed, and tested in accordance with safety and security requirements. Safety and security certifiable elements are those elements that are to be proven to be safe and secure prior to the startup of revenue service.

Safety and Security Certification shall be applied at the beginning of each project phase, and completion of Certification activities for that project phase is required for advancing project elements into the next project phase.

Mitigations identified through the Hazard Management and TVA processes described in Sections 32.5 and 32.6 respectively shall be verified for completion and validated for effectiveness using the Verification and Validation (V&V) process described in the VVMP. Each safety and security certifiable element shall be considered Safety and Security Certified when the V&V process is successfully completed.

Detailed procedures and forms for Certification can be found in the SSMP.

32.8 Construction Safety and Security

The HST System shall be designed so as to avoid, eliminate, or minimize the hazard risk to employees, contractors, the general public, or the environment during the Construction Phase.

The HST System shall be designed so as to maintain a secure environment during the Construction Phase.

Chapter 33

Fire Life and Safety

HSR 13-06 - EXECUTION VERSION

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Tables

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Figures

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Acronyms

33 Fire Life and Safety (TBD)

TBD. This topic may be included in a future revision of the Design Criteria or will be included in another document.

Appendix

Design Terms

Design Terms

2x25 kV Autotransformer System:	A Power Supply scheme for electrified railways that utilizes a Catenary energized at 25 kV to ground and an along track Negative Feeder also energized at 25kV to ground. The 25 kV catenary and 25 kV negative feeder supplies are derived via connections to an Autotransformer or the secondary winding of a Main Transformer, which results in a phase difference of 180° between the voltages, giving 50 kV between the high voltage bushings.

A

Abandoned Mines:	A collective term referring to the mapped or otherwise known presence of subsurface voids resulting from man-made mining or other subsurface tunneling activities.
Absolute Block:	A section of track into which a train is not permitted to enter while it is occupied by another train, except as provided for by the rules.
Access Control:	Restriction of access to or from a highway or railway right-of-way or facilities.
Access Control System:	System which enables the Authority to control access to areas and resources in a physical facility or area.
Accessible Voltage:	That part of the Rail Potential under operating conditions which can be bridged by persons, the conductive path being conventionally from hand to both feet through the body, or from hand to hand (horizontal distance of one meter to a touchable point).
Accessibility:	The ease with which a site or facility may be reached by passengers and others necessary to the facility's intended function. Also, the extent to which a facility is usable by persons with disabilities, including wheelchair users.
Active Fault:	A fault that has either known or is suspected of having had tectonic movement within Holocene time (past 11,000 years).
Administrative Telephone (ATEL):	Telephones which provide fixed voice communications between Authority employees to conduct daily operations. Part of the Telephone Intercom System (TIS).

<u>Aerial Ground Wire (AGW):</u> See *Static Wire.*

<u>Aerial Structure:</u> Trackway section placed on a structure, other than a culvert, which spans above earthen, paved, or water surfaces including roadways, railroads, and water channels. *Also, called elevated guideway.*

<u>Aerodynamic Force:</u> Additional vertical force applied to the pantograph as a result of air flow around the pantograph assembly.

<u>Alignment:</u> The horizontal and vertical route of a transportation corridor or path.

<u>Ambient Noise Sensor:</u> Sensor which detects background noise to automatically adjust Public Address output level to maintain audible output level.

<u>Ambient Temperature:</u> Outdoor air temperature measured with a thermometer (or other temperature measuring device) and located so that it is protected from direct sunlight and wind effects.

<u>Americans with Disabilities Act (ADA):</u> Federal regulation establishing legal requirements for accessibility. The Act prohibits discrimination on the basis of disability in employment, State and local government, public accommodations, commercial facilities, transportation, and telecommunications.

<u>Approximate Location:</u> In regard to underground facilities, the "approximate location of subsurface installations" being a strip of land not greater than 24 inches on either side of the exterior surface of the subsurface installation. "Approximate Location" does not define depth.

<u>Arc:</u> Electrical discharge which breaks down the insulation characteristic of air, permitting current to jump across the space between two contacts.

<u>Arcing (Pantograph):</u> The flow of current through an air gap between a pantograph contact strip and the contact wire, which results in erosion of both elements and is usually indicated by the emission of intense light, and which can result in radio frequency interference.

<u>Area of Impact:</u> The area of required utility construction or relocation due to the CHSTP.

Area of Influence: The area parallel to and 900 ft transverse to the centerline of the nearest track, or as defined in the Environmental Document, whichever is greater.

At-Grade: At ground surface level; used to describe roadways, river crossings, and track alignments.

Attenuation Relationship: Semi-empirical relationship to predict ground motions from a specific seismic source and event.

Attenuation Time: The time required for the vehicle motion to stabilize after crossing a point of change in the nature of the alignment.

Aspect: The appearance of a wayside signal, conveying an indication, as viewed from the direction of an approaching train; the appearance of an On-board Cab Display as viewed in the cab.

Authority: California High-Speed Rail Authority.

Authorized Person: Any person who has been authorized by the Agency to enter restricted areas of the property.

Automatic Train Control (ATC): The collective name for the train control subsystems that comprise the Automatic Train Protection, the Automatic Train Operation, and Automatic Train Supervision sets of functions that govern train operations on the main tracks.

Automatic Train Control Mode (ATC Mode): A mode of operation which allows the Locomotive Engineer to control the acceleration and braking of a train subject to supervision of Automatic Train Protection.

Automatic Train Control Bypass Mode (ATC Bypass Mode): A mode of operation which allows trains to proceed under the manual control of the engineer when there is an on-board ATC failure. Permission to break the ATC seal and enter this mode must be granted by the train dispatcher. Movement must not exceed the speeds prescribed by the operating rules and procedures.

Automatic Train Control – Automatic Train Operation Mode (ATC-ATO Mode): A mode of operation in which the ATC system controls the acceleration and braking of a train subject to supervision of Automatic Train Protection.

Automatic Train Control Territory: Territory equipped with ATC wayside equipment.

Automatic Train Operation (ATO): The functional set responsible for the automatic operation of throttle and brake commands to move trains between stations and other stopping locations (including those required due to the proximity of other trains and signal status) within the constraints imposed by the ATP functional set. Provides dwell timing at stations and the control or prompting of the opening and closing of train doors.

Automatic Train Protection (ATP): The functional set responsible for the safety-critical functions including those of interlocking, train detection, signal aspects, broken rail detection, hazard detectors (if implemented as part of the ATC system), and movement authorities (including speed limit and cab signal commands if appropriate) that are sent to the train and acted upon by the on-board train control to enforce safe limits. The ATP functional set includes the enforcement of the safety-critical functions. PTC functions are part of ATP.

Automatic Train Supervision (ATS): The functional set within the automatic train control system that is responsible for the centralized supervision and control of train movements; the ATS monitors trains, adjusts the performance of individual trains to maintain schedules, and provides data to adjust service to minimize inconveniences otherwise caused by irregularities. ATS also provides automatic and manual route setting at interlockings and the identification and tracking of trains, the display of alarms and events, and logging and storage of event data.

Autotransformer: Apparatus which helps boost the OCS voltage and reduce the running rail return current in the 2X25 kV autotransformer feed configuration. It uses a single winding having three terminals. The intermediate terminal located at the midpoint of the winding is connected to the rail and the static wires, and the other two terminals are connected to the catenary and the negative feeder wires, respectively.

B

Backslope: Resultant excavation face located between outer shoulder line and natural ground line.

Back-of-House Area: Area dedicated to station operational and support functions, with access restricted to station employees.

Backwater: An unnaturally high state in stream caused by obstruction or confinement of flow, as by a dam, a bridge, or a levee. Its measure is the excess of unnatural over natural stage, not the difference in state upstream and downstream from its cause.

Ballast: Crushed rock layer on which the track is laid.

Ballasted Track: Rail lines installed over a specific type of crushed rock that is graded in such a manner that can support heavy loads of the rolling stock.

Ballast-less Track: See Non-Ballasted Track.

Barrier: A device intended to contain or redirect an errant vehicle by providing a physical limitation through which a vehicle would not typically pass.

Barrier Offset Distance: The lateral distance from the centerline of the track to the face of the barrier, trackside, or other roadside feature.

Base Flood: The flood having a one percent chance of being equaled or exceeded in any given year. This is the regulatory standard also referred to as the "100-year flood".

Betterment: Improvements to the capacity and/or functionality of a utility system that is not required for safety, operation, and construction of the CHSTP.

Blanket: A layer of coarse grained material between ballast and subgrade, spread over entire width. It may be required over the formation where the subgrade soil is of poor quality, rainfall is heavy, and traffic density is high, as the absence of blanket in such cases can lead to problems in service.

Block: A length of track of defined limits on which train movements are governed by information provided by the On-board Cab Display, by interlocking signals, or by authorized manual methods.

Blockage Ratio: Ratio of train cross section area to tunnel cross section area.

Brake Horsepower: Actual horsepower applied to a fan shaft by the motor.

Broadband Radio System: Part of the Radio System, designed to transmit high-bandwidth data between moving high-speed trains and the fixed wayside.

C

Cab: The location on a locomotive or high-speed train set from which the engine or train is operated by the locomotive engineer. The location on an IMV from which on-track maintenance vehicle is operated by the driver.

Cable Infrastructure (CI): The fiber optic and copper infrastructure and supporting equipment used to interconnect systems and field device equipment.

Cantilever: A frame for supporting and registering the OCS conductors, often including solid core insulators; for auto tensioned systems, the cantilever connections at the pole are hinged to accommodate along track movement of the conductors, thereby allowing the end of the cantilever away from the pole to swing.

Capable Fault: A mapped or otherwise known Quaternary fault with evidence of Holocene displacement, structural relationship to related Holocene faults, and/or where data are not sufficient to rule out the presence of Holocene movement.

Casualty: A serious injury or fatality.

Catenary: An assembly of overhead wires consisting of, as a minimum, a messenger wire, carrying vertical hangers that support a solid contact wire which is the contact interface with operating electric train pantographs, and which supplies power from a central power source to an electrically-powered vehicle, such as a train.

Center Platform: Passenger platform in-between two station tracks.

Check Rail: The guiding rail located between the two running rails, which functions to maintain a derailed wheel within the track structure.

Closed Circuit Television (CCTV): The use of video cameras to transmit a visual signal to specific places with limited viewing and recording.

Code: A type of legislation that purports to exhaustively cover a complete system of law on a specific subject matter to define a procedure or performance requirement.

Cohesive Subgrade: Subgrade constructed with soils having cohesive behavior, i.e., soils where shear strength is predominantly derived from cohesion of the soil is termed as cohesive subgrade. Normally, soils having particles finer than 75 micron exceeding 12% exhibit cohesive behavior. All fine grained soils and GM, GM-GC, GC, SM, SM-SC and SC types of soils exhibit cohesive behavior. Acronyms are from the Uniform Soil Classification System.

Cohesionless Subgrade: Subgrade constructed with cohesionless, coarse-grained soils, i.e., soils where shear strength is predominantly derived from internal friction of the soil and is termed as cohesionless subgrade. GW, GP, SW and SP types of soils fall in this category. Acronyms are from the Uniform Soil Classification System.

Communications Interface Cabinet (CIC): A stand alone cabinet containing racks used for Communications and SCADA equipment.

Concourse: Open space for the gathering or passage of patrons.

Connectivity: Describes the degree of "connectedness" of a transportation system such as a transit network, and the ease with which passengers can move from one point to another within the network, or points outside the network.

Consist: A set of rolling stock that forms a train in service, a consist for HST can be a single trainset or more than one coupled together.

Constant Rate Spiral: The most common type of spiral. The radius increases at a linear rate over the length of the spiral. Commonly called a clothoid.

Contact Force: The sum of forces for all contact points of one pantograph.

Contact Point: Point of mechanical contact between a pantograph contact strip and a contact wire.

Contact Wire: A solid grooved, bare aerial, overhead electrical conductor of an OCS that is suspended above the rail vehicles and which supplies the electrically powered vehicles with electrical energy through roof-mounted current collection equipment - pantographs - and with which the current collectors make direct electrical contact.

Contact Wire Height: Height of the underside of the contact wire above top of rail level when not uplifted by the pantograph of an electric train.

Containment: Engineered structure (steel, concrete or earthworks) designed to maintain a vehicle within a defined area.

Containment Curb: Low concrete structure that maintains a derailed train into a guided way by maintaining its wheels inside a defined area.

Contours: A variable curve that connects points with the same elevation value used to depict surface elevations on a contour map.

Control: An established point on the earth's surface with a known position in the X, Y, Z coordinates and used for reference and mapping of field surveys.

Control Center: The location from which remote control signal appliances and switches are operated and operational decisions are made. On the CHST system these control centers are designated as:

- Operations Control Center (OCC) – The main control center located in the Central Valley that has direct control of all main track operations outside those areas controlled by the Regional Control Centers and general supervisory oversight of all railroad operations system-wide.
- Regional Control Center (RCC) – Two RCCs, one each located in Northern and Southern California will have direct control of all main track operations on the Peninsula Corridor and LOSSAN Corridor, respectively.
- Yard Control Center (YCC) – The yard component of the Heavy Maintenance Facility (HMF) and the Terminal Storage and Maintenance Facilities (TSMF) will each have a YCC staffed by a yardmaster and a train dispatcher who will be jointly responsible for direct control of operations, including all remotely controlled signals and switches, within the limits of the yard.

Controlled Access: Refer to "Access Control".

Conventional Rail: Traditional intercity passenger rail services of more than 100 miles with as little as 1 to as many as 7-12 daily frequencies; may or may not have strong potential for future high-speed rail service. Top speeds of up to 79 mph generally on shared track. Intended to provide travel options and to develop the passenger rail market for further development in the future.

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Counterpoise: A buried wire or a configuration of wires constituting a low resistance grounding system or portion of a grounding system.

Customer Assistance Intercom (CAI): Intercoms installed for passengers to report emergencies or obtain general travel information from local or remote Authority personnel. CAIs have two buttons for these two different functions. Part of the Telephone Intercom System.

Customer Information Monitor: A visual information device that is full color and able to display detailed image information from the PACIS system. Part of the PACIS system.

Customer Information Sign: A visual information device that is monochrome and able only to scroll text information from the PACIS system. Part of the PACIS system.

Cut-and-Cover: Construction technique in which a trench is excavated, infrastructure is installed, and the trench is closed.

Cut and Fill: Construction technique involving excavation or grading followed by placement and compaction of fill material.

D

Datum: A reference from which measurements are made for establishing horizontal and vertical control.

Dead Load: Static Load that is relatively constant throughout the life of a structure.

Dedicated Corridor: A segment of right of way within the CHST System where the main tracks are used exclusively for HST operations only, designated as such in the operating rules, and where these main tracks are completely separated physically from all other railroad tracks. The operation of trains (passenger and freight), other than the HST, over these tracks, is strictly prohibited in the operating rules and by regulation.

Dedicated Track: A main track designated in the operating rules for the exclusive use of CHST operations. All other train movements, passenger and freight, are prohibited and restricted by the operating rules and by regulation. It may or may not be in a Dedicated Corridor.

Degree of Curve:	The central angle turned by a curve in 100 feet. It is closely approximated by Dc = 5730 feet / Radius. Railroad curves are defined by the Chord Definition, in which the length is described by a 100 foot long tangent between two points on the arc of the curve. The exact formula for chord definition curves is Dc = 2 * arcsin (50 / Radius).
Derail:	A track safety device designed to guide a locomotive or car off the rails at a selected spot as a means of protection against collisions and other accidents.
Design Basis Earthquake (DBE):	Greater of (1) ground motions having a 10% probability of exceedence in 100 years, or (2) the deterministic median plus ½ sigma ground motion from the maximum characteristic earthquake from Class A seismic sources as defined by the California Geological Survey (CGS).
Design Criteria:	The direction for design of the system. The Design Criteria consist of mandatory items in the Design Standards and preferred items in the Design Guidelines.
Design Frequency:	The recurrence interval for hydrologic events used for design purposes.
Design Guidelines:	Provide a preferred but not necessarily required direction for a particular design feature. Guidelines are designated by the word “should’ or “may”. .
Design Life:	The projected period of time for which a design element will perform while meeting minimum specifications under a particular maintenance regimen.
Design Method:	Load and Resistance Factor Design (LRFD) methods are preferred for force based structural and geotechnical design. Performance based design to be used for MCE and DBE structural design.
Design Speed:	The maximum permissible speed along a segment of alignment based on the design specification of the track infrastructure, signaling system characteristics, and the maintenance specifications for that class of track.

Design Standards: Indicate required directions for a particular design feature. Language relating to standards will typically include the word "shall". An approved design variance is required for any deviation from the standards (see "Exceptional" below).

The design standards (classifications) presented in these documents will normally be described using three terms:

Desirable: The standard which shall be equaled or exceeded where there are no constraints. In regard to the alignment, desirable horizontal and vertical standards may be used in any combination.

Minimum/Maximum: The standard which shall be equaled or exceeded where constraints make a Desirable standard unobtainable or significantly more expensive than Minimum/Maximum standards. Even if a Desirable standard is not obtainable, it shall be approached as nearly as practical.

Exceptional: The standard which shall be achieved at the absolute minimum and only where Minimum/Maximum standards are either unobtainable or exorbitantly expensive. Even if Minimum/Maximum standards are not obtainable, they shall be approached as nearly as practical. An approved design variance is required for the use of an Exceptional standard.

Design Storm: That particular storm which contributes runoff which the drainage facilities were designed to handle.

Desirable: See Design Standards.

Digital Terrain Model: A three-dimensional model of digital surfaces of topographic features.

Directivity and Near Source Effects: The effects of direction of fault rupture and closeness to the fault on ground motion.

Disconnect Switch: A no-load interrupting type electrical switch for disconnecting electrical power from a line section.

Dual Control Switch: A power operated switch that may also be operated by hand. Dual control switches are found only within the limits of a yard.

Dwarf Signal: A low wayside signal with minimal preview that is used to provide adequate preview of the aspect displayed to high-speed trains.

Dwell: The time from wheel stop to wheel start of a train performing a scheduled stop at a station.

Dynamic Envelope of Pantograph: A clearance envelope around the pantograph static profile that takes into account the pantograph sway and pantograph uplift under dynamic conditions.

Dynamic Outline: Also called Kinematic Envelope. It is the trace of the maximum limits of movement of the vehicle in normal service. This outline is defined by the limits of motion due to wear of various components to their limits and includes deficiencies, such as deflated / overinflated airbags, etc. When defined from the perspective of the vehicle, it normally does not include any track deviations. When defined from the perspective of the infrastructure, track deviations are included.

E

Earthwork: A general term applying to excavations and embankments, and the movement of soil and rock.

Electric Lock Switch: A hand-operated switch, typically restricted to yards, that is equipped with an electrically controlled device that restricts the movement of the switch.

Electrical Clearance – Dynamic (Passing): The minimum permissible clearance distance between the OCS messenger wire, contact wires, pantograph, or other live parts of either the vehicle or OCS and the grounded vehicle load gauge, overhead structure, or other adjacent fixed structure under dynamic operating conditions, such as during the passing of a train or the movement of the conductors due to heating or climatic conditions.

Electrical Clearance – Static: Minimum clearance between live parts of either a vehicle pantograph or the OCS, , and grounded (earthed) parts of either a vehicle or adjacent fixed structure, while the vehicle and the live parts are stationary.

Electrical Clearance - Safety:	The distance in a straight line between a standing surface accessible to persons and energized parts necessary to prevent direct contact with energized parts, as defined in EN 50122-1: 1997 Section 5.
Electrical Section:	This is the entire section of the OCS which, during normal system operation, is powered from an SS circuit breaker. The SS feed section is demarcated by the phase breaks of the supplying SS and by the phase breaks at the adjacent SWS or line end. An electrical section maybe subdivided into smaller elementary electrical sections.
Elementary Electrical Section:	This is the smallest section of the OCS power distribution system that can be isolated from other sections or feeders of the system by means of disconnect switches and/or circuit breakers.
Electromagnetic Field (EMF):	The force field that extends outward from any moving electrical current, consisting of both a magnetic field and an electric field.
Electromagnetic Interference:	An electrical emission or disturbance that causes degradation in performance or results in malfunctions of electrical or electronic equipment, devices, or systems.
Emergency Intercom:	Intercoms installed for passengers to report emergencies and have a single button to perform this function. Part of the Telephone Intercom System.
Emergency Telephone (ETEL):	Telephones adjacent to the motor-operated OCS disconnect switches. These telephones are used by Authority staff to contact the Traction Electrification Power coordinator to report emergencies. Part of the Telephone Intercom System (TIS).
Embankment or Fill:	In regard to earthwork for track bed, artificial mound of imported material generally made of selected earth, gravel, or stone; built to support the HST when the reference line of the longitudinal profile is above the natural ground.
Entrance Facility:	A room in a building where cabling terminates. Cabling may be Authority cabling, third party cabling, or both.
Epoch:	As used in surveying, a specific date (time stamp) that all positions are based upon.

Equilibrium Superelevation:	The calculated superelevation that exactly balances the lateral force of the train on the curve at the defined speed. Normally called Balancing Cant or Equilibrium Cant in European publications.
Erosion:	The loosening, dissolving, or wearing away of earth materials in response to weathering, interaction with flowing water, wave action, or wind.
Exceptional:	See Design Standards.
Exclusive Use Corridor:	See Dedicated Corridor.
Expansive Soils:	Soils that undergo swelling and shrinkage when wetted and dried.

F

Fail safe:	For railroad related safety: A design principle the objective of which is to eliminate the hazardous effects of a failure of a component or system. For non-railroad safety related design: A design feature that ensures that the system remains safe or in the event of a failure will cause the system to revert to a state which will not cause a mishap.
Fare Collection Line:	Demarcation between Free Area and Paid Area.
Fare Gate Array:	Physical barrier which requires a valid CHST ticket to pass.
Fare Gates:	Physical barrier which requires a valid CHST ticket to pass. Also referred to as a Fare Gate Array.
Fault Hazard Zone:	Overall zone within which deformations related to fault rupture may occur and should be considered in the design.
Feasible:	Capable of being implemented.
Feeder:	A current carrying electrical connection between the OCS and a traction power facility (SS, SWS or PS).
Feeder Route:	Branch routes that feed into main (arterial) routes.

Fiber Optic Cable System:	A data transmission technology that relies on light rather than electricity, conveying data through a cable consisting of a central glass core surrounded by layers of plastic. Part of Cable Infrastructure.
Fire Alarm System (FAS):	System which monitors the station areas, control centers, facilities, and ancillary areas including spaces located within tunnels for fire; initiates alarms; activates the fire suppression systems; alerts the monitoring and response organizations to the incident; and assists in the fire emergency evacuation processes.
Flyover:	A bridge that carries one road or rail alignment aerially over another.
Footprint:	Area of the ground surface covered by a facility or affected by construction activities.
Foreslope:	In fill sections, the resultant slope of the fill that allows to safely support track and road subgrade and that places the subgrade at safe height above the maximum water and flooding level.
Formation:	It is a general term referring to the whole of blanket, subgrade, and subsoil.
Formation Top:	Boundary between ballast and top of blanket or subgrade (where blanket layer is not provided).
Free Area:	Areas within a station which are open to the general public.
Freeboard:	The vertical distance between the level of the water surface usually corresponding to the design flow and a point of interest such as a bridge beam, levee top or specific location.
Free Cross Section Area:	The standard tunnel cross section area excluding clearance for tunnel design details and fixed equipment.
Frequency:	The number of times a field, such as an electromagnetic field, changes direction in space each second. Also, the number of trains, flights, or other transportation service occurring in a given time period.

Frog (Turnout):

- Fixed Frog: Term essentially synonymous with Frog. "Fixed" is sometimes used as part of the name on railroad systems that also use spring frogs and swing nose frogs in order to clarify the type of frog used in a given situation.
- Spring Frog: A frog without a fixed open flangeway on one side between the frog point and wing rail that has springs holding that wing rail up against the frog point on that side so as to provide unbroken wheel support for the main track. The other wing rail is fixed. Main track traffic travels on the fixed wing side of the frog, not moving the frog. The wheels of diverging side traffic opens the sprung wing rail which is then forced closed by the spring after the wheel has passed. Spring frogs are either right handed or left handed. These devices are normally used only where the traffic on the side springing the wing rail is 20 percent or less of the total traffic over the frog. These devices are generally unknown outside North America.
- Swing Nose Frog: A frog in a turnout with a movable frog point connected to a switch machine for manipulation relative to the switch position.
- Point of Frog: In American terminology, the point where the gauge lines are 1/2 inch apart, or the point located one-half the distance in inches from the intersection of the gauge lines of the rails through the frog. In European terminology, the theoretical point of intersections of the gauge lines of the rails through the frog. The point, as defined in European terminology, is usually called the theoretical point of frog in American terminology.
- Heel of Frog: End of rails that are part of the frog assembly on the end away from the switch
- Toe of Frog: End of rails that are part of the frog assembly on the end toward the switch.
- A frog is commonly called a Crossing in European terminology.

G

Gantry: Portal frame spanning a railroad track or tracks for supporting and displaying signals, or installed parallel to the track(s) at TPFs to support disconnect switches and for connecting feeder cables from the TPF to the OCS.

Global System for Mobile Communications - Railway (GSM-R): An international wireless communications standard for railway communications. GSM-R is a sub-system of European Rail Traffic Management System (ERTMS). It is used for communication between train and railway regulation control centers for communication and control.

Geographic Information System (GIS): An information management system designed to store and analyze data referenced by spatial or geographic coordinates.

GEOID09: Gravimetric hybrid geoid height model developed by NGS containing the separation between NAD83 and NAVD88 and is the basis for elevations (orthometric heights) using GPS survey methods.

Geosynthetics: Structural elements made of synthetic materials for use in earthworks and construction of track bed layers. A distinction is made between:

- Geotextiles: Geosynthetics (woven or non-woven), which may be used for separation, filtering, drainage and reinforcement.
- Geomembranes: Geosynthetics (synthetic or bituminous layer) impermeable to water, which may be used for protection of sensitive subgrade against penetration of surface water or for protecting ground water against pollution.
- Geogrids: Fine or coarse mesh geosynthetics, which may be used for separation and reinforcement.
- Geocomposite: Compound structure made of at least two layers of geosynthetic materials.

Global Positioning System (GPS): A space-based global navigation satellite system that provides location and time information in all weathers and at all times anywhere on or near the Earth when and where there is an unobstructed line of sight to four or more GPS satellites.

GPS Network Time System (GNTS):	Time system which provides accurate time-of-day synchronization to devices and systems within the CHST. For example, wall clocks will be field devices of the GNTS.
Grade Crossing:	The intersection of a railroad and a highway at the same elevation (grade); an intersection of two or more highways; an intersection of two railroads.
Grade, Gradient:	The slope of changes in elevation, defined in percentage %, as feet of rise in 100 feet. Sometimes defined in European publication as millimeters of rise in one meter, in which case it is normally written as ‰.
Grade Separation Structures:	In respect to CHST: • Underpass: HST passes under roadway or other railroad. • HST Overpass: HST passes over roadway or other railroad. • HST Aerial Structure: HST is elevated. HST passes over roadways, bikeways, and other railroads where they occur. • HST Bridge: HST passes over water feature. In respect to Roadway Structures: Refer to Caltrans Nomenclature.
Grade-Separated:	At different elevations; on separate levels.
Grid:	A system of interconnected power generators and power transmission lines that is managed to meet the requirements of electrical energy users connected to that transmission system at various points.
Ground Grid (Mat):	A buried grid for installations, such as substations and disconnect switch platforms, which provides a low resistance path to ground and reduces touch-and-step potentials for operators of the equipment.
Ground Potential Rise (GPR):	The maximum electric potential that a substation grounding grid may attain relative to a distant grounding point assumed to be at the potential of remote earth. The GPR is equal to the maximum grid current times the grid resistance to earth.
Ground Rod:	A metal rod driven into the ground with ground wire connection to structures or equipment to disperse currents to ground (earth).

<u>Ground Wire:</u> A conductor installed for the purpose of providing electrical continuity between a device or equipment and a grounding system.

<u>Grounded:</u> Connected to earth through a ground connection or connections of sufficiently low impedance and having sufficient current-carrying capacity to limit the build-up of voltages to levels below that which may result in undue hazard to persons or to connected equipment.

<u>Groundwater:</u> Water contained and transmitted through open spaces within rock and sediment below the ground surface.

<u>Guard Rail:</u> A short guidance rail in the track. When a wheel passes over a switch frog in a non-guided section, the opposite wheel is guided by the guard rail, which acts on the back of the wheel flange.

<u>Guard Railing:</u> A metal railing acting as a safety barrier at the side of a freeway, highway or road to prevent errant vehicles from leaving the traveled way.

<u>Guideway:</u> A track or riding surface that supports and physically guides vehicles specially designed to travel exclusively on it. For the CHSTP, use "trackway" in lieu of guideway.

<u>Guidelines:</u> Non-mandatory, recommended, and supplemental information regarding generally acceptable methods to satisfy provisions of a regulation, code, standard. *In regard to the CHSTP Design Manual application, see Design Guidelines.*

H

<u>Hazard:</u> Hazards encompass all aspects of technology or activities that produce risk. Hazards include the characteristics of things and the actions or inactions of people.

<u>Hazardous Fault:</u> A fault that meets the following criteria: ≥1.0 mm/year Slip Rate (SR) and/or ≤ 1,000 year Recurrence Interval (RI).

<u>Hazardous Minerals:</u> Naturally occurring minerals contained within soil or rock that contain minerals known to be harmful if inhaled, ingested, or in contact with skin.

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<u>Headspan:</u> An across-track support arrangement comprising two or more wires that provide support for one or more OCS equipments. Headspans can be attached to two separated poles or to wayside buildings or other fixed structures.

<u>Headway:</u> The time between trains at a given point. For example, a 15-minute headway means that one train arrives, departs or passes every 15 minutes.

<u>Heavy Maintenance Facility (HMF):</u> A yard facility located in the Central Valley that provides overnight and mid-day rolling stock storage, and Level 1 to 5 maintenance capabilities.

<u>Help Point Intercom (HPI):</u> Intercoms installed for passengers to communicate with Authority personnel to report emergencies and obtain general travel information. HPIs have two buttons for these two different functions. Part of the Telephone Intercom System (TIS).

<u>High Risk Utility:</u> Utilities/Facilities conducting the following materials, whether encased or not, are considered to be High Risk:

1. Petroleum products.
2. Oxygen.
3. Chlorine.
4. Toxic or flammable gases or liquids.
5. Natural gas in pipelines of any size.
6. Underground electric supply lines, conductors or cables that have a potential to ground of more than 300 volts, either directly buried or in duct or conduit, which do not have concentric grounded or other effectively grounded metal shields or sheaths.
7. Water in pressured pipeline 6 inches or greater in diameter or pipelines of any size with normal operating pressure greater than 60 psi.
8. Other utilities that could disrupt the operation of CHST system.

<u>High Signal:</u> A signal located such that its aspect can be detected by train operators sufficiently in advance of the time the train passes the signal such that the train operator can identify the aspect and take proper action by the time the train reaches the signal.

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High-Speed Main Tracks:	Tracks used exclusively for the operation of high-speed trains.
High-Speed Train:	Train designed to operate safely and reliably at speeds near 200 mph (320 kph).
High-Speed Railroad:	A railroad system utilizing steel-wheel-on-steel-rail technology with a regular operating speed greater than 125 mph (200 km/h).
Highway-Rail (Hi-Rail) Vehicle:	A type of Infrastructure Maintenance Vehicle equipped with both rubber tires and steel wheels allowing it to operate on either a highway or railroad track.
Holocene Fault:	Fault with most recent movement within the past 11,000 years.
Home Signal:	A signal (wayside or virtual) at the entrance to an interlocking to govern trains entering the interlocking.
Human Machine Interface (HMI):	The user interface to systems or equipment. It is the space where interaction between humans and machines occurs.
Hut:	Small self contained enclosure to protect and secure specialized equipment.

I

Impedance Bond:	An electrical device located between the rails consisting of a coil with a center tap used to bridge insulated rail joints in order to prevent track circuit energy from bridging the insulated joint while allowing the traction return current to bypass the insulated joint. The center tap can also be used to provide a connection from the rails to the static wire and/or traction power facilities for the traction return current.
Indication:	The information conveyed by the appearance of the On-board Cab Display in the cab. The information conveyed by the aspect of a fixed wayside signal.
Infrastructure Maintenance Vehicle (IMV):	Infrastructure maintenance equipment operated on track for inspection or maintenance that may not shunt track circuits or operate signals.
Insulated Joint:	A joint in the running rail used to prevent track circuit energy on one side of the joint from leaking to the other side of the joint.

Insulated Overlap:	A sectionalizing point in the catenary formed by cutting insulation into the out-of-running conductors of the two adjoining and overlapping catenaries, having between them in the overlap span an electrical clearance realized by an air gap. The contact and messenger wires of these two overlapping tension lengths that terminate at opposite ends of the overlap section create a sectionalizing point in the catenary as required for operational and maintenance reasons, and permit the passage of pantographs under power from one energized electrical sub-section to the next, both supplied by the same traction power source.
Integrated Information Management Platform (IIMP):	Platform which integrates and leverages information from multiple stand-alone communications systems and other devices and systems for streamlined and coherent operation, monitoring, and control.
Interceptor Ditches:	Above a cut slope, they carry runoff from the watershed served and prevent surface runoff from entering the cut.
Interlocking:	An arrangement of signals (wayside and/or virtual) and switch appliances so interconnected that their movement must succeed each other in proper sequence and for which interlocking rules are in effect.
Interlocking Signals:	Fixed signals which govern the movement of trains through Interlockings that are observed by the train operator under ATC failure conditions at reduced speed.
Intermediate Station:	Any station between two terminal stations. Intermediate HST stations will include additional tracks to allow for through running express services.
Intermodal:	Describes transportation that involves more than one means (walk, bike, auto, transit, taxi, train, bus, air, etc.) during a single journey.

Interoperability: In the context of the European High Speed Lines, the capability of the European High-Speed lines railway network to permit high speed trains to run safely and continuously with specified performances. It is based on legal, technical and operational conditions that must be fulfilled to satisfy the necessary requirements. Thus, for example, a German high-speed train satisfying the requirements of the Rolling Stock Technical Specification for Interoperability (TSI) is able to run safely and continuously on a French High-Speed Line, the infrastructure of which satisfies the requirements of the various infrastructure Technical Specifications for Interoperability. These TSI design standards were developed specifically for the design, construction and operation of interoperable high-speed railways in Europe and are based on European and international best practices.

Intrusion: Entry of errant vehicles, goods, objects and people into the operating space of HST or other transportation system. An errant vehicle's exit out of its right-of-way and entry into the operating space of another transportation system's right-of-way.

Intrusion Detection System: An electronic system that alerts the Control Center of an intrusion event and may result in train movement restriction.

Intrusion Protection: Physical structure or space which will prevent entry of errant vehicles, goods, objects, and people into the operating space of CHST or other transportation system.

Island Platform: Passenger platform located between two station tracks.

K

Karst Terrain: A type of topography that is formed by subsurface dissolution of minerals, including mapped or otherwise known subsurface naturally occurring or man-induced voids.

Kiss-and-Ride: Facility for private vehicles to drop off or pick up CHST patrons.

L

Land Subsidence: The gradual downward settlement or sinking of the ground surface.

Landslide:	Mapped or otherwise known rock falls, mud flows, debris flows, landslides, and other forms of slope failures.
Lead (Turnout):	The distance from the actual point of switch to the 1/2 inch point of frog.
Level of Service (LOS):	A rating using qualitative measures that characterize operational conditions within a traffic stream and their perception by motorists and passengers.
Life Cycle:	All phases of the system's life including design, research, development, test and evaluation, production, deployment (inventory), operations and support, and disposal.
Line Side Drains:	Drains which collect and discharge surface water, seepage water, and ground water into a controlled outlet. Generally a distinction is made between buried drains, open channels, and side ditches.
Liquefaction:	Reduction of soil strength because of excess pore water pressure due to earthquake ground shaking when saturated.
Live:	An electrically energized circuit or component.
Live Load:	Load that varies due to dynamic factors within the normal operating cycle, but excluding seismic effects.
Live Part:	A part or component connected to an energized circuit and therefore live and not insulated from the energized circuit.
Local Area Network (LAN):	A network which provides network connectivity between terminals, servers, switches, sensors, and other electronic/optical equipment within a station or operational facility.
Longitudinal:	A facility located parallel to and within highway, existing railway, or proposed Authority right-of-way.
Low Risk Utility:	Facilities that are not covered under the definition for "High Risk Utility" are considered to be Low Risk Utilities.
Lower-level Design Basis Earthquake (LDBE):	Seismic ground motions having a 63.2% probability of exceedence in 100 years.

M

Main Track:	A track designated for the movement of trains at normal commercial speed having their movement protected by a control system. Tracks for the primary purpose of access to stations, yards, and other auxiliary facilities are not main tracks regardless of the presence or absence of movement protection system on those tracks. On CHST system, scheduled stops of any kind, including station stops will not normally be permitted on main tracks. On CHST system main tracks, all movements are protected by the ATC system.
Maintenance:	Regular activities that are required to support safe operations and the intended use of the high-speed train system such as inspection and correction of deviations from the design along the track.
Maintenance Management Information System (MMIS):	A system that provides various management and statistical functions to support the users in organizing the planning of rolling stock maintenance work and providing the relevant information necessary for decision making.
Maintenance Siding:	A stub end track dedicated to parking trains and connected to a passing track, never to the main tracks.
Major Utility:	Any subsurface, above ground, or overhead facility used for transmission, regardless of size, shape, or method of conveyance.
Maximum Considered Earthquake (MCE):	Seismic ground motions consistent with the current California Building Code (CBC) and ASCE 7-05 i.e., a 2% probability of exceedance in 50 years (or equivalently, 4% in 100 years) with deterministic limits as described in the CBC.
Maximum Authorized Speed (MAS):	The highest speed that is permitted over a specific portion of the railroad alignment. It may be authorized by special instructions of the current timetable, operating rules, or any other publication authorized by the chief operating officer.
Maximum Contact Force:	The maximum value of the contact force exerted by the pantograph on the contact wire. *Sometimes, maximum force.*
Mean Contact Force:	The statistical mean value of the contact force exerted by the pantograph on the contact wire. *Sometimes, mean force.*

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Medical Health Criterion: Maximum pressure variation (peak-to-peak value) in the tunnel (outside of the train) independent of time.

Messenger Wire: In catenary construction, the OCS Messenger Wire is a longitudinal bare stranded conductor that physically supports the contact wire or wires either directly or indirectly by means of hangers or hanger clips and is electrically common with the contact wire(s).

Minimum Contact Force: The minimum value of the contact force exerted by the pantograph on the contact wire. *Sometimes, minimum force.*

Minimum/Maximum: See Design Standards.

Minor Utility: Any subsurface, above ground, or overhead facility used as distribution lines or service laterals to individual parcels or properties

Modal: A transportation system defined on the basis of specific rights-of-way, technologies, and operational features.

Movement Authority: The vital information used by the on-board ATC system to determine the position on the track(or limit) to which the train can safely move under ATC supervision, including the speed limits both permanent and temporary that must be observed between its current position and the Movement Authority limit.

N

National Spatial Reference System (NSRS): Datum, defined and managed by the National Geodetic Survey, and the foundation for the National Spatial Data Infrastructure (NSDI).

Negative Feeder (NF): An overhead conductor supported on the same structure as the catenary conductors, which is at a voltage 25 kV with respect to ground but 180^0 out-of-phase with respect to the voltage on the catenary. Therefore, the voltage between the catenary conductors and the negative feeder is 50 kV nominal. The negative feeder connects successive feeding points, and is connected to one terminal of an autotransformer in the traction power facilities via a circuit breaker or disconnect switch. At these facilities, the other terminal of the autotransformer is connected to a catenary section or sections, via circuit breakers or disconnects.

Network Management System (NMS):	A system used to provision, test, and maintain network connectivity.
Neutral Leads:	The wires connecting the center tap of impedance bonds to other impedance bonds and/or to traction power ground circuits.
Neutral Section:	*See Phase Break.*
Nominal Voltage:	Voltage by which an installation or part of an installation is designated. The operating voltage of the OCS may differ from the nominal voltage within defined permissible tolerances.
Non-Ballasted Track:	Rail lines installed over concrete slabs for support.
Non-operating Condition:	The environmental/climatic conditions under which trains will not be permitted to maintain continuous operation and revenue service will cease.
Non-public Area:	Station areas accessible only to station staff and secured against unauthorized entry with lockable doors.
Non-Standard:	See Exceptional under Design Standards.
Non-Vital:	A designation placed on a system, subsystem, element, component, or function denoting that satisfactory operation of such is not mandatory for safety.
North American Datum of 1983 (NAD 83):	The horizontal control datum for the United States based on the Geodetic Reference System 1980 and with a geocentric origin.
North American Vertical Datum of 1988 (NAVD 88):	The vertical control datum established for surveying elevations in the United States based on the General Adjustment of the North American Datum of 1988.

O

OCS Pole:	Vertical structural element supporting the overhead contact system equipment, which provides physical support, registration and/or termination of the OCS conductors including auxiliary wires.

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On-Board Cab Display (OCD):	A display located in the cab of a train or infrastructure maintenance vehicle that displays to the operator the current speed, allowed speed, approaching speed restrictions ahead within a defined distance, the required braking curve that must be adhered to in order to maintain schedule, and other necessary operating information.
Operations Radio System:	The voice and low-bandwidth data radio system for wireless communications between on-board equipment, mobile and portable users, and fixed users and systems. (If PSM-R is used, ORS may carry safety-critical train control data).
Operating Condition:	The environmental/climatic conditions under which trains will be permitted to maintain continuous operation, and for which the OCS shall provide full, uninterrupted, and acceptable performance.
Operating Envelope:	A zone delineated by HST tracks and OCS.
Operating Infrastructure:	HST infrastructure that is required for operation of HST. This includes infrastructure within operating envelope plus other HST facilities required for operation of HST such as TP facilities, wayside power cubicles, train control rooms, communication rooms, and cable troughs.
Operating Speed:	The highest in-service speed that is achievable by a trainset technology on a segment of alignment that conforms to all of the requirements specified for that class of track. *See also Maximum Authorized Speed.*
Operations Control Center (OCC):	*See Control Center.*
Outboard Platforms:	Side boarding platforms located directly opposite one another, each serving one track.

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Overhead Contact System (OCS): OCS is comprised of:

1. The aerial supply system that delivers 2x25 kV traction power from substations to the pantographs of high-speed electric trains, comprising the catenary system, messenger and contact wires, stitch wires and hangers, associated supports and structures (including poles, portals, headspans and their foundations), manual and/or motor operated isolators, insulators, phase breaks, conductor termination and tensioning devices, downguys, and other overhead line hardware and fittings.
2. Portions of the Traction Power Return System consisting of the negative feeders and aerial static wires, and their associated connections and cabling.

Overhead Contact Line Zone and Pantograph Zone: The zone whose limits, in general, are not exceeded by a broken overhead contact line in the event of a dewirement or by a damaged pantograph or broken fragments thereof which are energized.

Overlap: *See Uninsulated Overlap and Insulated Overlap.*

Owner: In the context of utility coordination, the owner of the underground or above ground utility or its authorized agent.

Ownership: Any interest in land, real estate, or the improvements on it.

P

Paid Area: Areas on the platform side of the fare-paid line where possession of a valid CHST ticket is required.

Pantograph: Current collector apparatus consisting of spring-loaded hinged arms mounted on top of electrically powered rail vehicles that provides a sliding electrical contact and collects current from the contact wire of the overhead contact system. The pantograph is designed to follow changes in the vertical height and lateral offset of the contact wire, and to provide for essentially vertical movement of the pantograph collector head.

Pantograph Clearance Envelope: A clearance envelope around the pantograph static profile.

Pantograph Current: Current that flows through the pantograph.

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Pantograph Head:	Pantograph equipment comprising the current collector strips and their mountings.
Pantograph Sway (Pantograph lateral displacement):	Lateral displacement of the pantograph induced, under the dynamic passage of the electric vehicle, by vehicle and pantograph lateral displacements that include gauge deviation, roll and lateral vehicle shock loads, and cross-track tolerance.
Parallel Feeder:	*See Negative Feeder.*
Paralleling Station (PS):	An installation which helps boost the OCS voltage and reduce the running rail return current by means of the autotransformer feed configuration. The negative feeders and the catenary conductors are connected to the two outer terminals of the autotransformer winding at this location with the center terminal connected to the traction return system. The OCS sections can be connected in parallel at PS locations.
Parcel:	A distinct, continuous portion or tract of land.
Park and Ride:	Facility where CHST patrons can park and leave personal vehicles prior to transfer to HST.
Passenger Aural Comfort Criteria:	Maximum pressure change inside the train within a specified period of time to limit the discomfort on passengers' ears when passing through a tunnel.
Public Address and Customer Information Sign System (PACIS):	System which provides synchronized audio and visual information to passengers and Authority personnel using Public Address speakers and Visual Signs.
Passing Track:	A designated track connected to a main track on both ends for the purpose of allowing a train to clear the main track as a part of normal operations, usually for the purpose of accessing a station platform, allowing train overtaking, or allowing trains to clear the main tracks to minimize delay in case of operational issues. For regulatory and signaling purposes the passing track is treated the same as a main track.
Peak Period:	Time period during the day with the greatest volume of CHST patrons.
Performance Based Design:	In regard to seismic design, a design based on specific performance criteria in addition to building code based safety criteria.

Performance Criteria:	In regard to seismic design: No Collapse Performance Level (NCL) for which no collapse under MCE. Safety Performance Level (SPL) for which the system shall have repairable damage under DBE. Operating Performance Level (OPL) for which the system shall be designed such that the trains can operate at their optimum speed under LDBE.
Phase Break:	An arrangement of insulators and grounded or non-energized wires or insulated overlaps, forming a neutral section, which is located between two sections of OCS that are fed from different phases or at different frequencies or voltages, under which a pantograph may pass without shorting or bridging the phases, frequencies or voltages.
Photogrammetry:	The art, science, and technology of obtaining reliable information about physical objects and the environment through process of recording, measuring, and interpreting images and patterns of electromagnetic radiant energy and other phenomena.
Pick-Up and Drop-Off:	Facility for private and semi-private vehicles to drop off or pick up CHST patrons, which could include facilities for taxis, private shuttles, and rental cars.
Plat:	A plan or map of a plot of ground.
Platform:	Station area adjacent to tracks where trains stop to allow passengers to board and alight.
Portal:	In regard to OCS, see Portal Structure.
Portal Structure:	An OCS structure consisting of a crossbeam or truss supported by two separate OCS poles usually placed to the outside of multiple tracks to support OCS conductors. OCS support brackets or drop pipes are attached to the beam or truss to support the OCS cantilever frames.
Positive Train Control (PTC):	FRA-mandated train control requirement that automatically enforces train separation, collision avoidance, speed restrictions, and movement authority. On CHST ATP fulfills this requirement.
Potentially Hazardous Fault:	Fault having known or documented Holocene activity or known Quarterly faults with suspected Holocene activity.

Pothole / Test Pit:	An excavation to expose an underground facility.
Power Operations Controller (POC):	The authorized person in a Control Center who is permitted to operate and control TES equipment through the SCADA system and by voice commands to authorized field personnel and emergency response personnel, as applicable.
Power Transformer:	A device which transforms power on in ac system from one voltage level to another (e.g., from 115 kV to 25 kV).
Prepared Subgrade:	The upper layer of the subgrade is formed into a prepared subgrade layer, which normally has a cross slope. This layer is made of imported or treated material depending of the quality of the upper part of embankment or the bottom of the excavation. Its quality and compactness shall be better than the material below. Its function is to minimize the deformation of the upper part of the embankment or the bottom of the excavation and to prevent water that has passed through the subballast layer from penetrating to the earthwork below.
Pressure Comfort:	Conditions where there is no passenger ear discomfort due to pressure change.
Pressure Tightness Coefficient:	Time in which the difference between internal and external pressures upon a stepwise pressure change decrease from 100% to approximately 38% of the initial pressure difference.
Private Utility:	Utility infrastructure owned by a private corporation or public or private entities. They may not be regulated by the public or government agency.
Public Area:	Station free areas and paid areas, accessible to the general public.
Public Transportation:	Shared passenger transportation service available for use by the general public. Public transportation modes include buses, ferries, trolley buses, and various forms of rail transit including light rail, people movers, and grade separated "rapid transit" (metro/subways/elevated). Intercity public transportation includes airlines, buses, and intercity rail.
Public Utility:	Utility infrastructure that are operated and maintained for public service. Public Utilities can be either publicly or privately owned and involve natural monopolies in sectors specially regulated by the California Public Utilities Commission.

Q

Qualified Analyst: In regard to seismic design, an individual with the knowledge of engineering seismology and at least 5 years of experience in performing site specific deterministic and probabilistic seismic hazard analyses (DSHA and PSHA) in California.

Qualified Person: In regard to OCS and TES equipment, an authorized person who has been trained in and has demonstrated adequate knowledge of the installation, construction, maintenance, and operation of the OCS lines and TES equipment and the hazards involved, including identification of and exposure to electric supply and communications lines and equipment in or near the workplace.

Quality Level: A level of accuracy scale used for identifying the location of underground and above ground utility facility information needed to develop capital projects, and for acquiring and managing that level of information during the project development process. Four Levels of Quality Measurement are used ranging from Level A to Level D.

Quaternary Fault: Fault with evidence of movement in the past 1.6 million years.

Quantm System™: A proprietary route selection and optimization tool that carries out automated three dimensional alignment searches and corridor screening based on client- or user-specified geometry, constraints, and cost parameters. (Trimble Quantm Alignment Planning)

Queuing Area: Station area where passengers wait or line up to use a device or circulation element such as a ticket machine, fare gate, stair, elevator, or escalator. Queuing areas should be designed to accommodate waiting passengers without disrupting other passenger flows. Also, area provided to accommodate peak passenger surges.

R

Radio Frequency: The frequency range of the electromagnetic spectrum that is used for radio communication.

Radio System: Communications systems which use radio propagation to transport voice and data between fixed entities and systems and mobile entities and systems.

Rail Shared Corridor: See Shared Rail Corridor.

Rail Return: The combination of track structure, jumpers, impedance bonds, grounds, and cables, each of which provides part of the electrical return path from the wheel-sets of the traction units to a substation.

Rail Potential: The voltage between running rails and ground occurring both under operating conditions when the running rails are utilized for carrying the traction return current or under fault conditions.

Redundant Utility Supply Circuits: A configuration of two supply circuits from the utility supply company that originate from different transformers or bus systems. Using redundant supplies will minimize the possibility that power to both circuits will be lost simultaneously.

Refuge Track: A dead end track, normally connected to a station track, primarily for the purpose of temporary storage of a disabled train.

Regional Control Center (RCC): *See Control Center.*

Regenerated Power: Electrical power generated by electric vehicles when they brake by using their electric motors as electric generators.

Regulation: A rule and administrative code issued by governmental agencies at all levels – federal, state, county, and municipal that impose specific requirements and at times mandate permits or approvals by the agency (generally to ensure health and safety of the public). Although regulations are not laws, they have the force of law as they are adopted under authority granted by statutes.

Relocations: The removal, rearrangement, and reinstallation of a utility facility required by a transportation improvement project.

Response Spectrum: The response of damped single degree of freedom oscillators to an earthquake time history.

Restricted Area: An area for which a railroad agency has responsibility and to which access is permitted only to authorized persons.

<u>Restricted Manual Mode:</u> A mode of operation, enforced by the ATC system, which allows trains to proceed under the manual control of the locomotive engineer when there is an ATC malfunction. Permission to enter Restricted Manual mode must be granted by the train dispatcher. Movement must be at Restricted Speed subject to the prescribed operating rules and procedures.

<u>Restricted Speed:</u> A speed, not exceeding 20 MPH, at which it is possible to stop within one half the range of vision, short of the next signal, another train, obstruction, or derail, while looking out for broken rail or switch not properly lined.

<u>Retained Cut:</u> Trackway section where tracks are placed uncovered, below existing ground level and where adjacent soil is supported with retaining walls above top of rail elevation.

<u>Retained Fill:</u> Trackway section where tracks are placed on embankment material contained by retaining walls above existing ground.

<u>Return Circuit (Return System):</u> *See Traction Power Return System.*

<u>Richter Scale:</u> A logarithmic scale measuring the severity of earthquakes, based on the magnitude of ground motion.

<u>Ridership:</u> Number of passengers using CHST over a certain period of time.

<u>Right-of-Way:</u> A legal right of passage over a defined area of real property used for highway, railway, public utility services, or other purposes. In transportation usage, refers to the corridor along a roadway or track alignment that is controlled by a transit or transportation agency/authority and is usually the access control line.

<u>Risk:</u> In the consideration of hazards and vulnerabilities, a measure of the combined probability and severity of potential harm to one or more resources as a consequence of exposure to one or more hazards.

<u>Rolling Stock:</u> Wheeled railway vehicles.

<u>Rules:</u> Operating requirements found in the Code of Operating Rules, Special Instructions or other authorized CHST publications.

S

Safe Braking:	A set of design provisions and procedures which together ensure that a train's ATP stopping distance is safe in normal conditions and in all likely combinations of adverse factors and failure conditions.
Safe Point Intercom (SPI):	Intercom stations targeted for passengers to report emergencies only and have a single button to actuate this function. Part of the Telephone and Intercom System.
Safety:	The control of recognized hazards to achieve an acceptable level of risk.
Scale:	A graduated line representing a proportionate size.
Sealing Characteristics:	The capacity of the train to limit inside pressure change within given limits.
Section Insulator:	A mechanical sectionalizing device installed in the overhead catenary providing electrical separation between two adjacent catenary sub-sections both energized by the same traction power supply source which permits the passage of pantographs under power from one energized electrical sub-section to the next.
Security:	A means, active or passive, that serves to protect and preserve an environment and allows for the conduct of activities within an organization or society without disruption.
Seismic Hazards:	Earthquake-induced conditions such as vibratory ground motion, liquefaction, lateral spreading, dynamic compaction, seismically-induced slope failures, and ground rupture.
Seismic Source Model:	The geographic distribution of potential seismic sources that could affect the seismic ground motion at a particular site.
Service:	The portion of the electric, gas, water, sewer, or communication system that connects a customer, usually at the meter location, to the utility distribution or supply system.
Side Platforms:	Station area adjacent to a single track for the purpose of passenger boarding and alighting.

Shared Corridor: A portion of high-speed rail alignment where the high-speed trains operate on their own dedicated tracks parallel to and in the vicinity of other transportation systems such as highways, passenger railroads, or freight railroads.

Shared Rail Corridor: A type of Shared Corridor in which the other transportation systems are other railroads which may include passengers and freight.

Shared Track: A track designated in the operating rules for the operation of both the high-speed trains and other passenger or freight trains. Shared Track shall have time separation between the hours of operation of the passenger or freight trains and the high-speed trains (temporal separation). *Sometimes referred to as Shared Use Track.*

Shop Track: A designated track in a yard facility used for the maintenance or repair of rolling stock which is under the exclusive control of the Rolling Stock Maintenance employee in charge.

Signal Aspect: *See Aspect.*

Signal Block: *See Block.*

Signal Indication: *See Indication.*

Site Effects/Site Class: The effect of the subsurface soil/rock profile on the seismic ground motion and as classified in the CBC.

Sleeve: A pipe in which a pipeline or conduit is inserted. *Also, called casing.*

Slope Failures: Mapped or otherwise known slope failures such as rock falls, mud flows, debris flows, landslides, and other forms of slope failures.

Slope Stability: The ability of slopes to resist movement.

Slope Value: Slopes are defined as a fraction indicating the number of units of horizontal length required to achieve 1 unit of vertical distance, i.e., 2H:1V means the slope raises 1 unit vertically for 2 units of horizontal length.

Sound Powered Telephone (SPT): A telephone system requiring no power, used for first responders in tunnels. Part of the Telephone and Intercom System.

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<u>Span Length:</u> The distance between two consecutive OCS support points.

<u>Spiral:</u> Curve of variable radius used to connect a straight section of track with the radius of the body of the curve. *Sometimes called a Transition or a Transition Spiral*.

<u>Stagger:</u> Offset of the contact wire from the projected or super-elevated track centerline at each registration point that causes the contact wire to sweep side to side over the pantograph head during vehicle operation and which helps to distribute wear over the pantograph carbon collector strips.

<u>Standard:</u> Uniform criteria, methods, processes and practices developed by a regulatory body, agency, industry association, or organizations such as trade unions and trade associations, or other professional affiliations, that represent accepted requirement or a benchmark to measure against.

<u>Static Contact Force:</u> The mean vertical force exerted upward by the collector head on the overhead contact line, and caused by the pantograph-raising device, while the pantograph is raised and the vehicle is at standstill. *See also Contact Force*

<u>Static Gauge:</u> The maximum outline to which a vehicle may be fabricated. It will include only manufacturing tolerances.

<u>Static Wire:</u> A wire, usually installed aerially adjacent to or above the catenary conductors and negative feeders, that connects OCS supports collectively to ground or to the grounded running rails to protect people and installations in case of an electrical fault. In an ac electrification system, the Static Wire forms part of the traction power return circuit and is connected to the running rails at periodic intervals and to the traction power facility ground grids. If mounted aerially, the static wire may also be used to protect the OCS against lightning strikes. *Sometimes termed Aerial Ground Wire.*

<u>Station:</u> Areas within a station building envelope. Also, a place designated by name on the station pages of the current Timetable.

Station Intercom: Intercoms which allow the station attendant to communicate with passengers at fare collection equipment, fare-barrier equipment, or through protective glass. Part of the Telephone and Intercom System.

Station Track / Platform Track: A track for the purpose of bringing a train alongside a station platform for a stop to embark / disembark passengers.

Steady Arm: A lightly loaded registration arm that serves to hold or steady the contact wire at its correct lateral displacement/stagger.

Step Voltage: The difference in surface potential experienced by a person bridging a distance of 1 m (3'- 3") with the feet without contacting any ground object.

Structure Gauge: The outline defining the minimum distance from track centerline to various features.

Stub End: A track that terminates at one end.

Subballast Layer: An intermediate layer situated between the ballast and the subgrade layers. It protects the top of the embankment against erosion, ensures a better distribution of loads, and provides a leveled surface suitable for track laying. Subballast is made up of full crushed graduate gravel. This layer is referred to as the Blanket Layer in the UIC standards.

Subgrade: The top layer of earthwork upon which the subballast layer rests. On an embankment, the subgrade will be formed of imported soil, whereas in a cut, it will be the naturally occurring soil.

Subsidence: Sinking or lowering of the ground surface.

Subsoil: Soil of natural ground below subgrade.

Substation (SS): An electrical installation where power is received at high voltage and transformed to the voltage and characteristics required at the catenary and negative feeders for the nominal 2x25 kV system, containing equipment such as transformers, circuit breakers and sectionalizing switches. It also includes the incoming HV lines from the power supply utility.

<u>Subsystem:</u> A grouping of items satisfying a logical group of functions within a particular system.

An element of a system that, in itself may constitute a system.

In regard to HST, refers to the major operational part of the high-speed rail system, i.e. infrastructure, rolling stock, train control, electrification, operations, and maintenance.

<u>Superelevation:</u> The difference in elevation between the outside rail of the curve and the inside rail of the curve measured between the highest point on each rail head. Normally called Cant in European publications.

<u>Supervisory Control and Data Acquisition (SCADA) System:</u> System which provides centralized control and monitoring of multiple CHST systems.

<u>Switching Station (SWS):</u> An installation at which electrical energy can be supplied to an adjacent, but normally separated electrical section during contingency power supply conditions. It also acts as a PS.

<u>Switch (Turnout):</u> The component of a Turnout consisting of switch rails and connecting parts providing a means for making a path over which to transfer rolling stock from one track to another.

- Split Switch: Synonymous with Switch on modern railroads.
- Secant Point Switch: A switch point in which the arc of the radius of the switch rail or the turnout itself crosses the gauge line of the stock rail. American standard switch rails are Secant Point Switches.
- Tangent Point Switch: A switch point in which the arc of the radius of the switch rail or the turnout itself matches the gauge line of the stock rail. European and most other turnouts are designed to be Tangent Point Switches.

<u>System:</u> Grouping of items satisfying a logical group of functions.

<u>System Height:</u> The vertical distance between the messenger and contact wires, at the support structure. *Also known as System Depth*

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System Safety Engineering: An engineering discipline that employs specialized professional knowledge and skills in applying scientific and engineering principles, criteria, and techniques to identify and eliminate hazards, in order to reduce the associated mishap risk.

T

Telephone Intercom System (TIS): The system which provides mission critical voice communication functions for Authority personnel, Authority police personnel, third party emergency responders, and passengers.

Tension Length: Length of a catenary section between its two termination points. *Also known as Tension Section*

Tensioning Device: An assembly, typically placed at each end of a tension length, which comprises a balance weight arrangement that is used to maintain near-constant mechanical tension in one or more conductors of an auto-tensioned catenary.

Terminal Control Facility (TCF): A control center located at terminal stations that will have immediate supervisory oversight over train and passenger operations within each specific terminal. TCF personnel will ensure that appropriate information is relayed to passengers either automatically or manually, and directly manage the station facility and operations on a local level. Actual dispatching of trains will be controlled by main line dispatchers at the OCC or RCCs who will interface closely with TCF personnel.

Terminal Station: The first or last station of a passenger rail route.

Terminal Storage and Maintenance Facility (TSMF): A yard facility located near a terminal that provides overnight and mid-day rolling stock storage and Level 1 to 3 maintenance capabilities. In Phase 1 there will be a Northern California TSMF (NCTSMF) near San Francisco and a Southern California TSMF (SCTSMF) near Los Angeles.

Ties or Sleepers: Beams placed horizontally and laid perpendicularly to the rail to hold the rails to gauge, distribute the load of the track and equipment to the underlying support, and hold the track in horizontal and vertical alignment. Ties are normally between 8 feet and 8.5 feet long, except those supporting turnouts may be up to 16 feet long. The material normally used in CHSR track will be concrete, but ties may be of wood in yard turnouts and certain other special cases.

Time History: The values of acceleration, velocity, or displacement with time for an earthquake.

Top of Rail: Refers to the top of the rail on the track which defines the profile elevations of the track. On curves with superelevation, it is the top of the inside rail, also commonly called the top of low rail.

Topographic Map: A map of the features of the surface of the earth considered collectively as to form.

Touch Voltage: The potential difference between the ground potential rise (GPR) and the surface potential at the point where a person is standing while at the same time having a hand in contact with a grounded structure (Per IEEE-80).

Track Bed Layers: General term that includes the material imported for the foundation of the track. It includes the ballast and the following elements when present:

- Subballast layer
- Prepared subgrade
- Geosynthetics

Track Centerline: The line equidistant between the inside faces of the rail heads of a track.

Track Centers: Distance between adjacent track centerlines.

Track Circuit: A method of determining occupancy of a section of track and/or a broken rail by sending an electrical signal down the track from the transmit end to the receive end of the section of track, which indicates that the section of track is complete and not occupied by a train by detecting a minimum level of the proper signal at the receive end.

Track Formation Level: Surface intended to receive the track bed layers.

<u>Track Foundation:</u> Constitutes ballast, blanket, and subgrade which is placed/exists below track structure to transmit load to subsoil.

<u>Traction Electrification System (TES):</u> The combination of the traction power supply system (TPS) and the overhead contact system (OCS) together with the traction power return system, a supervisory control and data acquisition (SCADA) system, which forms a fully functional system, and which provides the electrical energy to the electrically powered vehicles on the CHST railway line.

<u>Traction Power Facilities (TPF):</u> A general term that encompasses substations (SS), switching stations (SWS) and paralleling stations (PS).

<u>Traction Power Return System:</u> All conductors, including the grounding system for the electrified railway tracks, which form the intended path for the traction return current from the wheel-sets of the traction units to the substations under normal operating conditions and the total current under fault conditions. The conductors may be of the following types:

- running rails
- impedance bonds
- static wires, and buried ground or return conductors
- rail and track bonds
- return cables, including all return circuit bonding and grounding interconnections
- earth

and, as a consequence of the configuration of the autotransformer connections, the negative feeders.

<u>Traction Power Supply System (TPS):</u> The railway electrical distribution network used to provide energy to high-speed electric trains, which comprises three types of traction power facilities in addition to connections to the OCS and the Traction Power Return System:

1. Substations (SS),
2. Switching Stations (SWS), and
3. Paralleling Stations (PS)

<u>Traffic Locking:</u> The enforcement of a single direction of operation in a track section.

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Train Control and Communications Room (TCCR):	An equipment room that houses all electronics, power, and networking necessary for the Train Control and communications functions.
Train Operator's Display:	An indication in the Train Operator's cab that provides the status of the ATC system and the safe limits within which the train may operate
Trainset:	A minimum set of rolling stock that can operate in service.
Transition Track:	A designated track connecting the main track to a yard facility designed to allow trains to safely reduce from and accelerate to main track speed. ATC rules are in effect on transition tracks. Movements will be governed by speed displayed on the On-board Cab Display, unless the train is in ATC Bypass mode, in which case it will proceed at Restricted Speed.
Transportation Demand Management:	The operation and coordination of various transportation system policies and programs to manage travel demand to make the most efficient and effective use of existing transportation services and facilities.
Transportation System Management:	Actions that improve the operation and coordination transportation services and facilities to realize the most efficient use of the existing transportation system.
Transverse:	A facility passing from one side of the right-of-way to the other side of the right-of-way.
Travel Time:	The time spent on a train from a place of origin to a place of destination.
Trolley Wire:	Alternative term for contact wire used for single wire OCS. See Contact Wire.
Tsunamis:	Waves that travel in the open ocean and are caused by an undersea earthquake, landslide, or volcanic activity.

U

Unbalance, Unbalanced Superelevation:	The difference between the Superelevation and Equilibrium Superelevation. In European publications, Unbalance is called Cant Deficiency (if the actual Superelevation is less than the Equilibrium Superelevation) and Excess Cant (if the actual Superelevation is greater than the Equilibrium Superelevation).

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Unbalanced Loads: Loads applied by a 3 phase transmission line that do not have the same load current across each of the 3 phases.

Uninsulated Overlap (or Mechanical Overlap): A length of the overhead contact system where the contact and messenger wires of two adjoining tension sections overlap before terminating at opposite ends of the overlap section. The two catenaries are jumpered together, thus allowing pantographs under power to transition from one tension length to the next.

Uplift: The vertical distance by which the overhead contact system is raised during the passage of a pantograph.

Upper Part of Embankment: Top three feet of an embankment. It requires high quality design and construction in order to ensure the appropriate bearing-capacity to receive track bed layers.

Unstable Formation: It is yielding formation with non-terminating settlement including slope failure, which requires excessive maintenance efforts.

V

Variable Rate Spiral: A spiral with a defined variation in the change of radius, usually in the form of a sine wave curve so as to reduce the entry and exit change in the rate of change. Desirable in high-speed operation, particularly if the track is on a concrete base.

Variance: Approved deviation, or exception, from a Minimum design criteria or Minimum design standard.

Vertical Curve: Transition between grades. Normally parabolic in US and Asian practices and circular arc radii in European practices.

Vital: A subsystem, element, component, or functional requirement in a safety critical system that is required to be implemented in a fail-safe manner.

Volcanic: Mapped or otherwise known volcanic centers and/or hydrothermal activity associated with volcanic activity.

W

Watershed: The area that contributes water to a drainage system or stream.

Wayside Drainage:	Drainage system (enclosed pipes, ditches, precast channel) laid to collect and discharge surface water, seepage water, and ground water.
Wayside Facilities:	Facilities in close proximity to the trackway. It is inclusive of traction power, communications, and train control facilities and exclusive of tracks.
Wayside Power:	Electrical power provided from the utility grid to the electrified railroad right-of-way at convenient locations from the side of the rail tracks or corridor. Where utility feeds are not available, wayside power can be supplied by tapping the 25 kV ac parallel negative feeders with appropriate transformation.
Wayside Power Control Cubicle (WPC):	An enclosure for power supply equipment for operation of motorized disconnect switches and the associated SCADA equipment located at the wayside.
Wayside Signals:	Devices located along the right-of-way for providing information to the locomotive engineers relative to train operations as opposed to the cab signal displays that are located within the control compartment of the rolling stock.
Wide Area Network (WAN):	Network which consists of the hardware and software required to switch, manage, process, control, monitor, and delivery data traffic between field locations and central control facilities via the fiber optic and copper cable infrastructure. The WAN's purpose is to deliver system data between any points on the wired network in a secure and reliable fashion.
WiFi:	Wireless local area network (WLAN) based on the IEEE 802.11 standards.

Y

Yard:	Inclusive of: 1. Rolling stock yard where revenue service vehicles are stored and maintained. 2. MOI yard which supports maintenance of trackwork, structures, and other facilities.
Yard Control Center (YCC):	*See Control Center.*

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Yard Limits: The tracks governed by the YCC at a yard facility.

Yardmaster: The employee responsible for ensuring the coordination and availability of the rolling stock fleet to meet daily service requirements and who has overall responsibility for all activities in the yard facility

Yard Mode: A mode of operation within yard limits which allows trains to proceed under the manual control of the locomotive engineer at Restricted Speed not exceeding 15 MPH. Speed and yard signal compliance will be automatically enforced.

Yard Signal: A fixed signal within the designated limits of a yard facility that displays either a red or yellow aspect and governs movements within the limits of the yard facility. A yellow aspect indicates that a route is set and locked, and that the section of track between opposing yard signals within which the switches are located is unoccupied.

Yard Signal System: A means of train control wherein trains are operated in Yard Mode under the control of the locomotive engineer, subject to yard signal indications, speed restrictions and special instructions.

Yard Speed: Restricted Speed not exceeding 15 MPH, within yard limits.

Yard Track: A section of track used for storage of trains that is auxiliary to the main track and not used by trains that are carrying passengers. Refuge tracks at stations are yard tracks. Yards consist of more than one yard track used for storing trains, inspecting trains, and accessing maintenance facilities. Yard tracks may or may not have track circuits on them.

Yoke Plate: A plate or casting typically proportioned to accommodate unequal tensions in two or more wires or cables that are terminated on one side and which are balanced by a single terminating cable on the other side, permitting the use of only one balance weight arrangement for multiple catenary conductors.

1

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